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ON THE ORIGIN OF THE AMPHIBOLITES OF THE LAURENTIAN AREA OF CANADA[1]

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In a paper which appeared in the last number of this *Journal* an account was given of the development of the Grenville series in a great tract of the Laurentian Protaxis, some 4,200 square miles in extent, situated in the eastern part of the Province of Ontario, a study of which has recently been completed for the Geological Survey of Canada by Dr. A. E. Barlow and the writer.

In this tract the Grenville series is not only of great areal extent but is of enormous thickness. About one-half of this thickness consists of limestone while the remainder consists of gneisses of sedimentary origin (paragneiss), with occasional quartzites and great bodies of amphibolite. This series is invaded by enormous bathyliths of gneissic granite and while in the southeastern portion of the area toward the margin of the Protaxis, the sedimentary series is comparatively free from igneous intrusions, toward the northwest the granite in ever increasing amount arches up the sedimentary series and wells up through it, in places disintegrating it into a breccia composed of shreds and patches of the invaded rock scattered through the invading granite, until eventually connected areas of the sedimentary series disappear entirely and over hundreds of square miles the granite and granite-gneiss alone are seen, holding, however, in

[1] Communicated by permission of the Director of the Geological Survey of Canada.

almost every exposure inclusions which represent the last scattered remnants of the invaded rock.

In addition to these intrusions of Laurentian granite-gneiss, there occur in the area, also cutting the Grenville series, great intrusions of gabbro and great bodies of nepheline syenite.[1] These massive intrusions of gabbro are frequently intimately associated with and partly inclosed by bodies of amphibolite which are classed as belonging to the Grenville series. The whole forms a very complicated and, at the same time, a very interesting stratigraphical complex, as will be seen by consulting the Bancroft or Haliburton geological map sheets recently issued by the Geological Survey of Canada. The former sheet is also to be found accompanying the paper on this region which has recently appeared in the *Quarterly Journal of the Geological Society of London.*[2]

The inability to determine the origin and, therefore, the significance of the bodies of amphibolite which occur abundantly not only in this district, but everywhere throughout the Laurentian, has always proved to be one of the chief difficulties in the way of a correct interpretation of the geology of this system. The same difficulty has been met with in the case of these and allied rocks occurring elsewhere, as, for instance, the trap granulites of the Saxon Granulit Gebirge, or the amphibolites of the crystalline complex of certain portions of the Alps, the origin of which remained in doubt while the rocks with which they are associated had been definitely determined.

It is the purpose of the present paper to present briefly the results of a study of the genetic relations of the amphibolites of this particular area in the Canadian Protaxis.

The amphibolites in the area in question present a considerable variety in character and appearance but have as common characteristics a dark-gray to black color and a basic composition. Hornblende and feldspar, the latter chiefly plagioclase, are the chief constituents of the rock. Quartz, which is one of the commonest constituents

[1] See Adams and Barlow, "The Nepheline and Associated Alkali Syenites of Eastern Ontario," *Transactions Royal Soc. Can.*, 1908.

[2] F. D. Adams, "The Laurentian System in Eastern Canada," *Q. J. G. S.*, 1908, p. 127.

in the associated gneisses, is absent or is present only in very small amount. Pyroxene or biotite often replaces the hornblende in part. The amphibolites are sometimes rather coarse, but usually medium or fine in grain, and they possess as a general rule a more or less pronounced foliated structure. They occur, as has been mentioned, associated, on the one hand, with the gabbro or diorite intrusions and as inclusions abounding throughout the granite of the bathyliths, and on the other hand they are often so intimately associated with certain developments of limestone in the form of interbedded layers that it has been found necessary to map the two rocks together and to designate them by a single color.

Two of the more common varieties of these amphibolites which occur associated with the limestones were, during the course of mapping, designated as "feather amphibolite" and "granular amphibolite." The first of these always occurs in thin bands interstratified with the limestone and derives its name from the curious feather-like development displayed by the large skeleton crystals of hornblende or pyroxene which are developed in the plane of the stratification of the rock and which give to the rock a striking appearance when it is split in this direction. The granular amphibolite, which also frequently occurs as heavy bands in the limestone, is of a finely granular character, without any very distinct foliation, and on the weathered surface presents a uniformly minutely speckled appearance, owing to the intimate admixture of minute grains of hornblende and feldspar.

As the result of a very careful examination, it is possible to prove conclusively that in this area the amphibolites have originated in three entirely different ways, the resulting rocks, although of such diverse origin, often being practically identical in appearance and composition. This remarkable convergence of type, whereby rocks of widely different origin come to assume a practical identity of character, explains the difficulty which has been experienced up to the present time in arriving at a satisfactory conclusion concerning their genetic relations.

These three modes of origin are as follows:

1. By metamorphism and recrystallization of impure calcareous sediments.

2. By the alteration of basic dykes and similar igneous intrusions.

3. By the alteration of limestone through the action of the intruding bathyliths of granite.

First mode of origin.—Some of these amphibolites result from the metamorphism and recrystallization of sediments. To this class belong the "feather amphibolites" above referred to, which usually occur in thin bands alternating with crystalline limestone and evidently of like origin. They represent siliceous, argillaceous, and dolomitic laminae in the original calcareous deposit. In many cases the bands of crystalline limestone become thinner and less abundant and the composite rock gradually passes over into a body of pure "feather amphibolite." This rock can, in certain parts of the area, be traced into a comparatively unaltered variety, so that its original character is definitely determinable. Whether the "granular amphibolite," which is also found very frequently and over wide areas alternating with bands of limestone, is in some cases of similar origin, it has not been possible up to the present time to determine.

Second mode of origin.—Certain granular amphibolites represent altered igneous intrusions, for they are found in the form of dykes cutting vertically across the stratified white crystalline limestone on the shores of Jack's Lake in the township of Methuen. The limestones here dip at a low angle to the south and are excellently exposed in the form of low cliffs about the side of the lake. The typical granular amphibolite can be seen rising above the surface of the water in the form of vertical dykes, cutting directly across the stratification of the limestone. These are one to two feet wide and can frequently be seen on reaching a certain bedding plane to have been bent over in the direction of the bedding which they follow, and to have been torn apart by movements in this plane, the limestone strata having, during their upheaval, experienced somewhat extensive movements along their bedding planes. The dykes, after having followed the bedding plane for a certain distance, once more cut vertically across the latter and so reach the surface. Such dykes when seen on limited exposure of the bedded surface of the limestone, especially in contorted districts, would usually present the appearance of interstratified masses of amphibolite.

This amphibolite has the regular allotriomorphic structure of a

completely recrystallized rock and differs from any of the normal igneous rocks. Under the microscope it is identical with an amphibolite described by Teall which was developed by the alteration of a diabase dyke where crossed by a line of shearing. In the case of these Canadian dykes, however, the amphibolite is not confined to that portion which has been clearly subjected to movement but forms the whole mass of the dyke. Seeing that this typical granular amphibolite can be proved to have originated from the alteration of a basic igneous dyke—in all probability originally a diabase—it is very highly probable that many other occurrences of this rock whose origin cannot be determined from their field relations may also be derived from the metamorphism of similar igneous intrusions.

Third mode of origin.—Amphibolites which are identical in physical character and in composition with those of class two are also produced by the metamorphic action exerted by the granite bathyliths on the limestones through which they cut. This is a remarkable fact and one which at first sight seems scarcely credible. It is, however, a change which has undoubtedly taken place on a large scale. The discovery that amphibolite originated in the manner just referred to explains what was a very puzzling fact in the early stages of the field-work in this region, namely, that while the granite bathyliths break through the limestone in all directions, they were filled with amphibolite masses and not with limestone inclusions. This fact was at first thought to be due to the granite happening to intrude portions of the limestone bands which were impure and thus held within themselves the material for the production of amphibolite by diagenetic rearrangment; but as occurrence after occurrence over the whole vast area was found to present the same phenomenon, it became evident that it was impossible to consider that the limestone strata had always happened to be impure at the places where the granite had broken through them, while elsewhere over great tracts the limestone contained little or no impurity. A critical study was therefore made of certain localities where the contact of the two rocks was well exposed and where the effects of the intrusion could be studied over a considerable range of country. This study showed conclusively that the limestone along its contact with the granite became impure through the development in it of bisilicates and plagioclase feldspar, and eventually when in

actual contact with the intruding rock that the limestone was changed into an amphibolite.

In addition to the amphibolites originating in the three ways above mentioned, it is highly probable, judging from their character and mode of occurrence, that the great amphibolite bands associated with large gabbro and diorite masses, as for instance that running in a northeasterly and southwesterly direction through the township of Wollaston, and that occurring in the southeast portion of the township of Cardiff, thence crossing Chandos into Anstruther, represent chiefly highly altered basic volcanic ashes and lava flows connected with vents represented by the gabbro stocks. The latter of these amphibolite bands presents a great variation from place to place in the character of the constituent rock. While in some places this amphibolite is well banded, elsewhere it is streaked or presents an appearance strongly resembling flow structure, with lighter colored, lathlike forms thickly scattered through it which are highly suggestive of feldspar phenocrysts, while elsewhere again it presents an appearance suggestive of an original amygdaloidal structure. The rock, however, is so completely recrystallized that a microscopic examination does not yield any conclusive evidence concerning its original character.

That amphibolites do originate in the first manner described is clearly seen and easily understood, and that they originate in the second manner referred to is well known and has been described in many localities, but that they may originate also in the third way above mentioned is not so generally recognized, and this mode of origin therefore merits a further consideration.

DEVELOPMENT OF AMPHIBOLITE AS ONE OF THE CONTACT PHENOMENA ABOUT THE BORDERS OF THE GRANITE BATHYLITHS

About the borders of the various areas of granite, contact action is pronounced and often very striking. If the invaded rock be amphibolite, fragments torn from it are found scattered about in the gneiss, in the form of inclusions.

When the granite invades bodies of limestone, on the other hand, the phenomena resulting from the intrusion are more varied. The invading rock metamorphoses the limestone and the products of alteration may be divided into three classes:

a) The alteration of the limestone into masses of granular greenish pyroxene rock, usually containing scapolite, or into a rock consisting of a fine-grained aggregate of scales of a dark-brown mica.

b) Intense alteration of the limestone along the immediate contact into a pyroxene gneiss or an amphibolite.

c) In addition to these alteration products, in certain cases the granite dissolves or digests the invaded rock, after having altered it in one or other of the ways above mentioned.

The alteration products of Class *a* may be considered as due to the heated waters or vapors given off by the cooling magma, that is to be of pneumatolitic origin, while the alteration products of Class *b* result from the more immediate action of the molten magma itself. The products of these two classes of alteration, however, have much in common and naturally pass into one another.

The most common product of the alterations of Class *a* is a granular pale-green pyroxene rock which occurs in the limestone at or near the contact with the granite. This pyroxene rock, resulting from the alteration of the limestone, varies considerably in texture from place to place, but is usually medium in grain and granular in character, the sahlite individuals of which it is composed being short and stout with a hypidiomorphic development. Associated with the pyroxene in this rock are black mica, hornblende, scapolite, epidote, garnet, sphene, spinel, zircon, tourmaline, pyrrhotite, pyrite, molybdenite, calcite, apatite, and occasionally quartz and feldspar, as accessory constitutents. Of these minerals the mica and hornblende especially have a tendency to occur in segregations or nests composed of very large individuals, so large in fact that the mica has been mined in these pyroxene rocks at several places in the area, in one case mica crystals, having cleavage surfaces measuring two feet by two feet and a half, having been obtained. The calcite, when present in the rock, is usually in the form of very coarsely crystalline aggregates, cementing the other constituents together and into which the other minerals grow in the form of perfect crystals with excellent terminations. This calcite represents portions of the original limestone which have survived in an unaltered condition, except that they have grown more coarsely crystalline. When the calcite is subsequently removed in solution by percolating waters, spaces result which when

broken into by mining are found to be lined with beautiful crystals of pyroxene or other constituents of the rock.

The other product of pneumatolitic action belonging to this class is a rock composed of an aggregate of small leaves of a very deep brown or black mica, and is less common. These mica rocks almost invariably contain more or less calcite disseminated through them, which on exposure to the weather is dissolved out, the weathered surface of the rock thus being disintegrated into a soft mass of small scales of mica. The chemical nature of this mica has not been determined, but it is probably a variety of lepidomelane, containing a considerable amount of fluorine and probably some lithia such as is found in limestones about granite intrusions in other parts of the world.

The alterations of Class *b*, whereby the limestones are converted into amphibolite, are especially well seen about the borders of the great Glamorgan bathylith whose eastern limit lies in the township of Glamorgan. This bathylith here breaks through the great body of limestone underlying the northwestern portion of the township of Monmouth and affords a most excellent and striking example of *lit-par-lit* injection. The character of this contact action can be excellently studied at Maxwell's Crossing, on Lot 15 of Range VI of the township of Glamorgan. Here the limestone, toward the granite contact, passes gradually over into amphibolite, the latter being undoubtedly produced by the alteration of the former. The invading granite in the form of apophyses wanders through the limestone series in all directions, sometimes cutting across the bedding, but very frequently in the form of narrow dykes forcing their way between the beds of the invaded limestone, changing it into amphibolite and presenting a typical instance of *lit-par-lit* injection. The granite, furthermore, not only penetrates the series, but floats off masses of the altered rock which, in the form of bands, streaks, and isolated shreds, are seen thickly scattered through the granite in the vicinity of the contact, and which, while less abundant, are found throughout practically the whole extent of this bathylith as mentioned below. The separate fragments of amphibolite where completely surrounded by the granite, while clearly nothing more than masses of altered limestone, are rather harder and more "granitized" in appearance than the amphibolite which is still interstratified with the limestone, and the

fragments sometimes have somewhat flowing outlines as if they had been subjected to a certain amount of movement when in a softened condition.

When examined in thin sections under the microscope the limestone which is in the act of passing into amphibolite is seen to do so by the development in it of certain silicates. These, when the change is complete, are so abundant that they have entirely replaced the calcite while in the intervening stages some of the original calcite still remains. These silicates belong to the following species: Pyroxene, hornblende, sphene, scapolite, plagioclase, microcline, orthoclase, and quartz. The relative abundance of these minerals varies in different bands and from place to place in the rock. Their characters are as follows.

The *Pyroxene* is rather deep green in color and shows an absence of pleochroism. It is one of the chief constituents, being in the earlier stages of the change present in large amount. It first appears in individuals which are rounded in shape, do not possess crystallographic outlines or any approximation to crystalline form. In those varieties rich in calcite, the sections of the pyroxene grains are frequently nearly circular.

The *Hornblende*, which at first is much less abundant than the pyroxene, is also green in color but it is a much deeper green than the pyroxene. The grains are similar to those of the pyroxene in form, but are usually less rounded. It is intimately associated with the pyroxene, often forming adjacent grains, but there is no conclusive evidence that one mineral is derived from the other. It is strongly pleochroic.

The *Sphene* is present only in a very small amount in the form of small rounded grains of a brown color.

Scapolite is usually present in considerable amount. It polarizes in brilliant colors, is uniaxial and negative, and shows the other microscopical characters of this mineral.

The *Feldspars* vary greatly in amount. In places they form a considerable part of the rock, while no scapolite is present. In other places the scapolite seems to take their place and they are reduced to the rank of accessory constituents. All three varieties of feldspar mentioned often occur in the same specimen, their relative

abundance varying from slide to slide. The polysynthetically twinned plagioclase in some cases equals the potash feldspar in amount, but usually the potash feldspars seem to be rather more abundant.

The *Quartz* is found only in a few of the thin sections and is there present only in very small amount.

When the *Calcite* survives, it can be seen that the original rock had the character of a coarsely crystalline limestone or marble. Under the action of the metamorphic processes the silicates have grown into it in the form of rounded grains which, increasing gradually in size, have finally left the calcite merely as a filling of the surviving interstitial spaces. The grains are about the same size as those of the other minerals.

An examination of thin sections of a suite of specimens of this amphibolite from a single series of exposures in the cutting on the line of the Irondale, Bancroft and Ottawa Railway at Maxwell's Crossing—some of them still containing little surviving bands of calcite and others of the harder and more altered varieties—shows that in the former pyroxene and scapolite accompany the hornblende and feldspars, while as the alteration becomes more pronounced these former minerals become less abundant and eventually disappear, giving rise to a rock composed of hornblende and feldspar, associated with which a little biotite is seen in some specimens, with certain accessory minerals which are common to both rocks. Although, as above mentioned, no actual passage of pyroxene into hornblende could be definitely observed, the hornblende individuals often have a minutely serrated edge where they come against the pyroxene, as if they were gradually enlarging themselves at the expense of the latter mineral and thus replacing it.

The amphibolite, representing the final product of the alteration, while possessing a more or less distinct foliation, has the "pflaster," "pavement," or mosaic structure characteristic of rocks which have resulted from recrystallization brought about by metamorphic processes. It presents no evidence of crushing or of having been caused to move since its recrystallization took place. This structure is quite distinct and different from that seen in the little injected bands of granite. In these, which are composed of quartz, microcline, orthoclase, and plagioclase, the quartz occurs for the most part in thin leaves with

undulatory extinction and the structure of the rock is suggestive of the "mortel" or granulated structure seen in the granite gneisses.

In this remarkable occurrence, therefore, the crystalline limestone can be seen under the influence of the granite intrusion to have changed into a typical hornblende feldspar amphibolite, having passed through the intervening stage of a pyroxene scapolite hornblende feldspar amphibolite (pyroxene scapolite gneiss).

Three specimens of these amphibolitic rocks from Maxwell's Crossing, chosen to represent three steps in the progressive change from limestone to amphibolite, were selected for analysis. The analyses were made by M. F. Connor, B.Sc., of the Geological Survey of Canada. The figures given are in every case the mean of two determinations which agree closely with one another. The results of these analyses are as follows:

	No. 1		No. 2	No. 3
	(*a*)	(*b*)		
SiO_2	32.88	50.20	50.00	50.83
TiO_2	0.49	0.75	0.82	1.10
Al_2O_3	9.04	13.80	18.84	18.64
Fe_2O_3	0.77	1.18	2.57	2.84
FeO	3.48	5.31	5.51	5.97
MnO	.....	.....	0.08	0.10
CaO	30.90	17.71	10.65	7.50
MgO	4.18	6.38	4.63	4.90
K_2O	0.85	1.30	1.18	1.83
Na_2O	1.17	1.79	4.46	4.22
CO_2	15.20	.....	0.10	0.11
Cl	undet.	.....	0.10	0.03
S	undet.	.....	0.03	0.01
H_2O	1.08	1.66	1.00	1.40
	100.04	100.08	99.97	99.48

No. 1 represents the first stage of alteration and was made from a specimen which shows an alternation of narrow lighter and darker colored bands. The specimen was broken across the strike of the rock and thus included several of each of these bands, giving in this way an approximate average of the composition of the rock as a whole. Under the microscope the lighter colored bands are seen to consist of calcite, pyroxene, and a little hornblende. In the darker bands the calcite is largely replaced by the silicates, the constituent minerals

of these bands being scapolite, pyroxene, some hornblende, some calcite, and a little microcline. A very small amount of sphene is also present in the rock.

The analysis as given under No. 1 *a* represents the composition of the specimen as collected; that given under No. 1 *b* represents the composition of the rock as it appears when the calcite present (determined by calculation from the amount of CO_2 present and also by direct experiment) is deducted and the amount of the remaining constituents is recalculated on the basis of 100. No. 1 *b* therefore represents the percentage composition of the silicated portion of the specimen, or, to put it in another way, it represents, except in the case of the lime, the additions made to the limestone by the granite magma in this first stage of alteration. The specimen contains 34.50 per cent. of calcite, leaving 65.50 per cent. of silicates. This silicated portion of the rock, as will be seen by comparing analysis No. 1 *b* with Nos. 2 and 3, bears a general resemblance in composition to the two latter rocks which represent the subsequent stages of alteration, the percentage of silica being practically identical in all cases.

No. 2 is the analysis of a typical specimen of the amphibolite which alternates with thin bands of the limestone at Maxwell's Crossing. It represents a second stage in the alteration, this particular specimen being practically free from calcite. Under the microscope it is seen to be composed of hornblende and pyroxene, more or less completely replacing each other in the alternate bands, together with a considerable amount of scapolite, plagioclase and untwinned feldspar. The rock also contains many minute rounded grains of sphene scattered everywhere through it, but holds no iron ore and no biotite.

No. 3 is the analysis of a harder variety, being a typical amphibolite and representing the last stage of the change. It occurs as an inclusion in the granite in the same series of exposures as that from which the other specimens were taken. The field relations show that it has been derived from variety No. 2 by further alteration. Although not differing much from No. 2 in chemical composition, under the microscope it is seen to differ considerably from it in structure, the individuals of the several constituents showing a less marked tendency to a rounded outline than in the case of No. 2. In mineralogical composition also it presents certain differences, the pyroxene and

scapolite having disappeared and a certain amount of biotite having been developed.

A comparison of the analyses shows that the granite at first transfuses into the limestone, silica, alumina, oxides of iron and magnesia, with some alkalis and a small amount of titanic acid. As the alteration progresses, all these constituents continue to increase in amount. But in these later stages of the alteration the alumina, oxides of iron, and alkalis are added in relatively greater proportion than the other constituents, while no further addition of magnesia or lime takes place, the proportion of these constituents remaining essentially the same, the carbonic acid escaping and carrying the rest of the lime with it.

This means, speaking generally, that pyroxene and some scapolite were first developed in the limestone and that later the feldspathic constituents increased in amount, the calcite present being removed in solution.

A calculation of the analyses shows that Nos. 1 *b* and 2 have the following mineralogical composition:

	No. 1 *b*	No. 2
Feldspathic constituents	48.57	67.35
Pyroxenic (iron magnesia) constituents	46.63	26.28
Iron ores	3.2	5.27
	98.40	98.90
Water	1.66	1.00
	100.06	99.90

During the change of No. 1 into No. 2 and this into No. 3, the information afforded by the analyses bears out that obtained from the study of the thin sections, showing that there has been a very considerable rearrangement among the constituents of the rock. Thus it is seen that while the alumina and alkalis increase in No. 2 and No. 3, there is not a corresponding increase in the total amount of silica; the silica required to make additional feldspathic constituents being derived from some other reactions going forward in the rock.

It seems also that after the development of a certain percentage of silicates in the limestone, as shown in No. 1, during which process

carbonic acid was expelled and the lime combined with it used in the production of new minerals, no further lime was fixed. In the earlier stages the waters given off by the granite having accomplished the transference of material into the limestone, passed off with the replaced CO_2 in solution, leaving the lime behind. In the later stages of the alteration, however, these waters, while continuing to deposit silicates in the limestone, made place for these latter by carrying off carbonate of lime in solution.

As will be seen, the difference in chemical composition between Specimen 2 and Specimen 3 is very small. The more highly altered rock, No. 3, is rather richer in iron, magnesia, and alkalis, while it is considerably poorer in lime and contains less chlorine. These differences are seen to represent a slight increase in the proportion of hornblende and orthoclase present and a decrease in the amount of plagioclase and scapolite in the rock.

If, for the purpose of comparing the composition of these alteration products with that of igneous rocks, the norms are calculated, these are found to be as follows. Since No. 3 is essentially the same as No. 2, the norm of the latter rock may be taken to represent both specimens and with it is given the norm of the silicated portion of No. 1 (No. 1 *b*).

	No. 2	No. 1 *b*
Orthoclase	7.23	7.74
Albite	26.20	15.24
Anorthite	27.94	25.59
Nepheline	5.56	.....
Sodalite	0.42	.....
Diopside	19.78	34.81
Akermanite	.....	6.97
Olivine	6.30	4.85
Calcite	0.20	.....
Ilmenite	1.52	1.40
Magnetite	3.71	1.80
Pyrite	0.04	.....
	98.90	98.40
Water	1.00	1.66
	99.90	100.06

In the quantitative classification the rocks, therefore, have the following position:

No. 2.		No. 1 *b*	
Class II.	Dosalane	Class III	Salfemane
Order 5	Germanare	Order 5	Gallare
Rang 3	Andase	Rang 4	Auvergnase
Subrang 4	Andose	Subrang 4	Auvergnose

While, therefore, the quantitative classification is intended to apply only to igneous rocks, this final product of the metamorphism of the limestone when compared with igneous rocks readily takes its place as an andose, a group which includes many rocks which are commonly known as diorites, gabbros, basalts, diabases, and essexites.

For purposes of comparison the analysis of this amphibolite (No. 2) is here repeated together with that of an amphibolite (No. 5) produced by the alteration of a basic igneous intrusion (probably a diabase originally) and with the analyses of three typical igneous rocks which have been produced by the solidification of molten magmas.

	No. 4	No. 5	No. 6	No. 7	No. 8
SiO_2	50.00	48.81	50.86	50.73	48.85
TiO_2	0.82	0.74	....	1.59	2.47
Al_2O_3	18.84	16.62	15.72	19.99	19.38
Fe_2O_3	2.57	1.17	9.77	3.20	4.29
FeO	5.51	7.47	2.48	4.66	4.94
MnO	0.08	0.12	....	0.05	0.19
CaO	10.65	10.30	10.52	8.55	7.98
MgO	4.63	8.28	3.55	3.48	2.00
K_2O	1.18	0.76	0.90	1.89	1.91
Na_2O	4.46	3.31	3.89	4.03	5.44
CO_2	0.10	0.55	....	....	....
Cl	0.10	0.03	....	....	not det.
S	0.03	0.06	....	....	....
P_2O_5	....	....	....	0.81	1.23
H_2O	1.00	0.95	2.53	0.77	0.68
	99.97	99.17	100.22	100.13*	99.36

* Including BaO 0.27.

No. 4. Amphibolite resulting from the alteration of limestone—Maxwell's Crossing—Lot 5, Range VI, Township of Glamorgan, Ontario.

No. 5. Dyke cutting limestone—Lot 27, Range VIII, Township of Methuen, Ontario.

No. 6. Gabbro, near Baptism River, Minnesota, U. S. A. (Wadsworth, *Geol. Survey of Minn.*, 2, p. 79, 1887).

No. 7. Diorite—Big Timber Creek, Crazy Mountain, Montana (Wolff, *Bull. U. S. G. S.*, 148, p. 144, 1897).

No. 8. Normal Essexite—Mount Johnson, Quebec (Adams, *Jour. of Geol.*, April-May, 1903).

The silicated portion of the half-altered limestone (Analysis 1 *b*), which in the quantitative classification would fall under Auvergnase, has certain igneous rocks which approach it rather closely in composition, although it is higher in lime than any igneous rock whose analysis has been hitherto recorded, as emphasized by the fact that akermanite appears as a standard mineral in its norm. The following igneous rocks resemble it most closely:

	I	II	III
SiO_2	48.11	46.15	46.16
Al_2O_3	16.98	13.57	13.86
Fe_2O_3	.....	3.61	5.26
FeO	7.82	8.15	1.81
MnO	1.88	.....	.....
MgO	5.67	12.63	11.60
CaO	17.75	15.15	15.74
Na_2O	1.82	1.29	1.05
K_2O	.....	.....	0.30
H_2O	.....	.....	3.40
	100.03	100.55	99.18

I. Saussurite gabbro, Yttero, Norway.

II. Hypersthene gabbro, Urals, Russia (Loewinson-Lessing, *G. Sh. Jushno Saos*, Dorpat, 1900, p. 166).

III. Gabbro (not fresh), Laurion, Greece (R. Lepsius, *Geol. v. Attika*, Berlin, 1893, p. 98).

In connection with this alteration of limestone to amphibolite it is to be noted that the change is not one of solution or digestion of the limestone by the granite, for the fragments preserve their sharp and well-defined forms even when the alteration is complete.

The limestone, at a distance from the granite, is a white crystalline marble, containing scarcely any impurities and effervescing freely in fragments with cold dilute hydrochloric acid, showing that it is an essentially pure carbonate of lime.

The granite which brings about this alteration has not been analyzed but is in all probability of essentially the same composition

as that of the adjacent Methuen bathylith, the analysis of which is given below:

SiO_2	73.33	CaO	1.66
TiO_2	0.17	MgO	0.45
Al_2O_3	13.55	K_2O	3.12
Fe_2O_3	0.58	Na_2O	5.01
FeO	1.53	H_2O	0.45
MnO	0.04		99.89

The changes are the result of the transfusion into the limestone of certain constituents which are present in the granite magma. A remarkable fact in connection with the alteration, is that the granite, which is an acid variety of the rock containing a very small amount of biotite as its only bi-silicate, where the limestone was bathed by it or actually immersed in it as in the case of the included fragments, has notwithstanding this fact transfused into the limestone not only silica, alumina, and alkalis, as might be expected, but also large amounts of magnesia and iron. The limestone evidently fixed certain constituents of the granite magma in relatively greater abundance than others, exerting a species of selective action. Many cases have been described in which a granite magma has passed by differentiation into a gabbro, but here the granite retains its normal character and at the same time changes the limestone into a rock having the composition of a gabbro.

That similar changes are brought about by the action of acid magmas upon limestones elsewhere is shown by two occurrences described by Kemp[1] and one by Lindgren. The first is from San José, in the State of Tamaulipas, Mexico, the second from Morenci, Arizona, and the third from White Knob, Idaho. In all cases highly acid intrusive rocks, quartz-porphyries or quartz-diorite-porphyries, very low in iron, penetrate limestones which are so pure that they can yield little or no garnet of themselves. In each case the intrusives

[1] J. F. Kemp, "Ore Deposits at the Contacts of Intrusive Rocks and Limestones and Their Significance as Regards the General Formation of Veins," *Economic Geology*, Vol. II, No. 1, 1907, p. 1, and *Trans. Am. Inst. Mining Eng.*, XXXVI, p. 192. W. Lindgren, *U. S. Geological Survey*, Professional Paper No. 43, p. 134. See also O. E. Le Roy, "The Marble Bay Copper District," *Jour. Can. Min. Inst.*, 1907, p. 248.

have developed in the limestones large amounts not only of an alumina garnet (grossularite), but also of an iron garnet (andradite), showing that the acid magma has transfused into the limestones large amounts of SiO_2, Al_2O_3, and Fe_2O_3, which the limestones have fixed in the form of garnet.

Kemp's conclusions concerning these occurrences exactly coincide with those reached from a study of the occurrences in the Haliburton-Bancroft area, as shown by the following quotations from the paper referred to above:

> First of all the question may be raised as to whether the eruptive has melted into its substance sufficient limestone to yield the zones which have then crystallized out from fusion. This view is opposed both by the sharp contacts afforded by the eruptive against the garnet zones; by the variability of the zones in mineralogy, and by the fact that the necessary ingredient of andradite would not thereby be afforded. In almost all cases the eruptive is a highly acidic rock, a quartz-porphyry, or quartz-diorite-porphyry. The percentage in iron is very small, far below the requirements of the iron-lime garnet, and the general composition not at all adapted to yield the zones. On the contrary we are irresistibly led to the conclusion that from the intrusive rock has come either highly heated water gas or highly heated water itself in the closing stages, and that one or both of these have brought to the limestone the silica, iron oxide, and alumina for the production of the lime-silicates. After the production of the garnet and its associates was well under way, they brought in also the copper and iron sulphides which are the commonest ores.
>
> The silica and the other dissolved materials did not wander farther from the eruptive because the limestone promptly intercepted them and locked them up in silicates; but undoubtedly carbonated water and carbon dioxide gas were yielded in great quantity, an inference which falls harmoniously in line with what we know of volcanic emissions.

A MIOCENE FLORA FROM THE VIRGINIA COASTAL PLAIN[1]

EDWARD W. BERRY
Johns Hopkins University

The later Tertiary of Europe is as remarkable for its extensive and representative floras, as is that of America for their absence, for with the exception of certain isolated florules of the Western Interior and Pacific coast region there are no known Miocene floras in America.

The Atlantic coastal plain Miocene, or Chesapeake Group, appears to be made up entirely of marine deposits carrying an abundant, chiefly molluscan fauna and furnishing but slight hints of the life which flourished along its shores. It has been correlated on the basis of its invertebrates by Dall and others with the Helvetian or Middle Miocene of Europe. The earliest member of the Chesapeake Group, the Calvert formation, is characterized in the Maryland-Virginia region by extensive beds of diatomaceous earth which rest with marked unconformity on the usually glauconitic sands of the Eocene or overlapping them to a notable extent in Virginia.[2]

While the Miocene of the world was in general a period of elevation it would seem as if this elevation was greatest in eastern North America in the interval which preceded the deposition of the Chesapeake Group, during which time the Eocene appears to have undergone great denudation, since the comparative purity of the diatomaceous beds of the Calvert formation seems to have been due to the lowness rather than to the remoteness of the adjacent mainland with the consequent lack of erosion. This supposition is fully borne out by the evidence of the flora discussed in the following pages.

Some years ago the Maryland Geological Survey discovered plant remains in the Calvert formation as exposed on Good Hope Hill which is situated in the District of Columbia just across the Anacostia

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] They of course rest on the older Cretaceous or the underlying crystallines in places where the Eocene is absent.

River from Washington. These were few and rather poor, but sufficient to form the basis for six species, all new, which were described by Dr. Arthur Hollick[1] in 1904. It is probable that an exhaustive search would disclose similar remains elsewhere in this immediate region, since the writer has seen fragmentary plant fossils from these same beds along the Bennings road near the District lines, and from the banks of the Choptank River and Tuckahoe Creek, on the Eastern Shore of Maryland. The only other eastern flora of possible Miocene age is that from the Bridgeton gravels of southern New Jersey which is understood to be quite extensive.[2] It also has been studied by Dr. Hollick but is as yet unpublished. It is considerably younger, however, than that of the Calvert formation and may possibly be of Pliocene age.

With these preliminary remarks we turn to a very interesting flora found in the Calvert formation at Richmond, Virginia. The presence of this flora was discovered by Dr. Benjamin L. Miller during a reconnaissance trip in 1906, but no collections were made until the present summer when the writer spent part of two days in making a thorough collection at this locality and it is upon this collection that the following notes are based. The Calvert formation at this point consists of very argillaceous diatomaceous earth forty to fifty feet in thickness, resting unconformably upon remnants of the Eocene or upon the underlying crystallines and overlain by Pleistocene deposits. That this locality was near the shoreline of the Miocene sea, as it is near the landward limit of the existing Calvert deposits, is indicated not only by the argillaceous nature of the materials as compared with similar diatomaceous deposits elsewhere in the Calvert formation, but by the contained plant fossils, as well as by considerable comminuted lignite, the latter forming layers 5–12 mm. thick in places.

Thirteen species are enumerated in the present communication and the doubtful fragments uncharacterized at this time include perhaps two or three more forms in addition to several varieties of seeds not yet identified. The species recognized include seven well-known and widespread Tertiary forms and one species, *Rhus milleri*

[1] Hollick, "Miocene," *Maryland Geol. Surv.*, 1904, pp. 483–86, Figs. *a–h*.

[2] A Miocene flora of considerable variety and extent, discovered within the last few months in North Carolina, is being studied by the writer at the present time.

Hollick, previously described from the Calvert formation of Maryland. Six species are described as new.

It seems evident that this is a localized flora and not one characteristic of the eastern American uplands during Miocene time, and we may compare the local conditions at that time with those which exist at the present day in the Dismal Swamp region, or, better still, with the innumerable cypress swamps which skirt the South Atlantic coast. There is the Miocene cypress (*Taxodium*) by far the most abundant fossil in these deposits and associated with it we find *Salvinia*, a floating plant in the modern flora. The seeds of a *Nyssa* represent that modern semi-aquatic genus. *Carpinus* and *Planera* are both low swamp and waterside types at the present day, as are a majority of the willows (*Salix*). *Platanus* inhabits wet situations as do also several species of *Fraxinus* and many species of *Ficus*. The oak (*Quercus*) is at home in the environment pictured, while the *Rhus*, *Celastrus*, and the two species of Leguminoseae are not at all out of place in such an association. The conclusion seems irresistible that in these fossiliferous Calvert deposits we have preserved some of the débris of a nearby cypress swamp, and that it was the presence of such swamps along the consequently low-lying coast where the streams were of necessity inactive, which effectually prevented any large amount of land-derived sediment from becoming a part of the Calvert formation. Citations are restricted to the more important references in the following notes:

Subkingdom Pteridophyta
Order Filicales
Family *Salviniaceae*
Genus Salvinia Adans
Salvinia formosa Heer?

Salvinia formosa Heer, Fl. Tert. Helv., 3:156. pl. 145. f. 13–15. 1859.
Velenovsky, Fl. Ausgebr. Tert. Letten v. Vrsovic, 12. pl. 1. f. 14–17. 1882.
Hollick, Bull. Torrey Club, 21:256. pl. 205. f. 6. 1894.
Zeiller, Fl. Foss. Gites de Charbon du Tonkin, 269. pl. 51. f. 2, 3. 1903.

This undoubted fragment of a Salvinia leaf has been doubtfully referred to the above species, with which it agrees in so far as its characters can be made out, rather than to adopt the course of founding a new species upon a single fragmentary specimen. Future

collections may furnish sufficient material for a complete diagnosis in which case the specific identity can be positively settled.

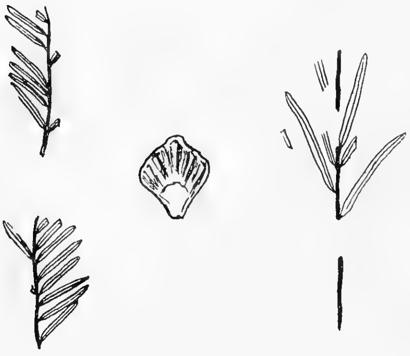

FIG. 1

Subkingdom Spermatophyta
Class GYMNOSPERMAE
Order CONIFERALES
Family *Pinaceae*
Subfamily *Taxodieae*
Genus Taxodium Rich.
TAXODIUM DISTICHUM MIOCENUM Heer

Taxodites dubius Sternb., Fl. d. Vorwelt, 204. 1838.
Unger, Iconogr., 20. pl. 10. f. 1–7. 1852.
Taxodium dubium Heer, Fl. Tert. Helv., 1:49. pl. 17. f. 5–15; 1855.
Taxodium distichum miocenum Heer, Mioc. Baltic Fl., 18. pl. 2; pl. 3. f. 6, 7. 1869.
Newb., Mon. U. S. Geol. Surv., 35:22. pl. 47. f. 6; pl. 51. f. 3; pl. 52. f. 2–4; pl. 55. f. 5. 1898.
Knowlton, Bull. U. S. Geol. Surv., No. 204:27. 1902.
Harriman Rept., 4:152. 1904.

This is by far the commonest fossil in these deposits indicating that the nearby shores were probably bordered by cypress swamps, thus furnishing a plausible explanation for the absence of terrigenous materials in the Calvert formation.

It is an exceedingly common and widespread Tertiary species ranging from the Eocene upward into the basal Pliocene (Messinian) and recorded from numerous localities throughout Eurasia from Japan and the Kirghiz Steppe to Italy, Prussia, France, and Switzerland. In the Arctic regions it has been found in Alaska, Grinnell Land, and Greenland, and in the United States it is recorded from Nevada, Wyoming, Montana, and Oregon.

It may be distinguished from the equally wide-ranging *Sequoia langsdorfii* by the markedly decurrent leaves of the latter.

The collection made at Richmond include, in addition to the leafy twigs, the characteristic cone-scale figured, which is slightly smaller than the usual scales of the existing species but otherwise exactly similar.

Class Angiospermae
Order SALICALES
Family *Salicaceae*
Genus Salix Linné
SALIX RAEANA Heer

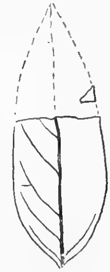

FIG. 2

Salix raeana Heer, Fl. Foss. Arct., 1:102, 139. pl. 4. f. 11–13; pl. 21. f. 13; pl. 47. f. 11. 1868.
Ibid., 2. ab. 4:469. pl. 43. f. 11a. 1871.
Ibid., 4. ab. 1:70. pl. 14. f. 8. 1877.
Ibid., 7:76. pl. 69. f. 2; pl. 86. f. 4. 1883.
Lesq., Proc. U. S. Natl. Mus., 11:17. 1888.
Knowlton, Bull. U. S. Geol. Surv., No. 204: 30. 1902.

The basal portions (about one-half) of two leaves of a Salix were found at Richmond, and, although incomplete, they agree so admirably with the numerous figures of this species given by Heer as to leave little doubt of their specific identity. They indicate a mediumly broad lanceolate leaf 3.5 cm. long by 1.3 cm. in greatest width, which was toward the somewhat rounded base.

This species was described originally from Greenland by Heer who afterward detected it in material from Spitzbergen, and in the Tertiary collection from near the north of the Mackenzie River made by Sir John Richardson's expedition. Lesquereux afterward identified it from the Mascall beds of Oregon, basing his determination upon material which Dr. Knowlton states (*loc. cit.*) is very poor and doubtful.

Order FAGALES
Family *Betulaceae*
Genus Carpinus Linné
CARPINUS GRANDIS Unger

Carpinus grandis Unger, Syn. Pl. Foss., 220. 1845.
Heer, Fl. Tert. Helv., 2:40. pl. 71. f. 19b–e; pl. 72. f. 2–24; pl. 73. f. 2–4. 1856.
Fl. Foss. Arct., 1:103. pl. 49. f. 9. 1868.
Ibid., 2:469. pl. 44. f. 11c. 1871.
Ibid., 3. ab. 2:14, 17. pl. 3. f. 14. 1874.
Ibid., 7:82. pl. 88. f. 4, 5. 1883.
Lesq., Tert., Fl., 143. pl. 19. f. 9; pl. 64. f. 8–10. 1878.
Velenovsky, Fl. Ausgebr. Tert. Letten v. Vrsovic, 23. pl. 2. f. 25; pl. 3. f. 1–6. 1882.
Knowlton, Bull. U. S. Geol. Surv., No. 204:38. 1902.

This is another of those widespread Tertiary species which may be composite although usually regarded as simply a variable type. The Richmond collections contain eight fragments of leaves which are referred with some little hesitation to this species. The venation is similar, although it must be admitted that it would serve equally well for Fagus, Betula, Ostrya, or Planera; the variability in size is in accord with that usually observed in this species as is also the general outline. Unfortunately the marginal characters, while they suggest this form, are not well enough preserved to be decisive, all of the leaves being macerated in exactly the same manner as are the delicate leaves of *Carpinus caroliniana* Walt. after they have floated down our southern rivers for a considerable distance.

Carpinus grandis makes its appearance in the Arctic Tertiaries, becoming rather widespread before the close of the Oligocene and is recorded from Europe, Asia, and America. It is more especially, however, a Miocene type and has been collected from a large number of European localities as well as from Japan and the Mascall beds of the John Day basin in Oregon. It persists into the Pliocene, being recorded from beds of that age in Styria and in Italy (Messinian).

Family *Fagaceae*

Genus Quercus Linné

QUERCUS MILLERI sp. nov.

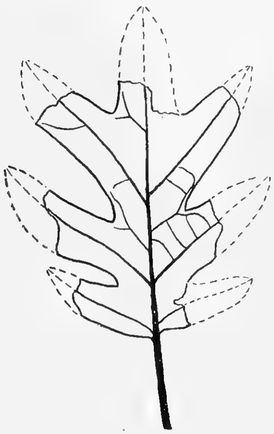

FIG. 3

Leaves about 5 cm. in length with a mediumly stout petiole 1.4 cm. long. Lobate, with three narrow rather obtusely pointed lobes on each side, each traversed by a prominent secondary whose angle of divergence is less than that of the lobes, the secondaries leaving the midrib nearly on a line with the basal margin of the lobes and running nearer their upper than their lower margin to the apex of the lobe. Basal lobes forming almost a right angle with the midrib, their lower margins being very obtusely rounded, almost truncated, to within a millimeter or two of the petiole and then curving slightly downward, their secondaries branching at an angle of 55° about one millimeter

above the top of the petiole, subopposite. The sinus which intervenes between the basal and the median lateral lobes is cut to within 4 or 5 mm. of the midrib and is narrow and acute and but slightly inclined. The median lateral lobes which are 50 per cent. longer than the basal pair, and also broader, are somewhat more ascending, the angle of divergence of their secondaries from the midrib being 46°. The next sinus is somewhat broader, widening out laterally. It is about the same depth as the lower sinus, terminating internally in a narrow obtuse point. The upper lateral lobes are about the same length as the median pair, but are more ascending, their secondaries diverging from the midrib at an angle of from 35° to 42°. The terminal lobe is 9 mm. wide at its base and of undeterminate length, probably about 1.5 cm., the sinus between it and the upper lateral lobes being broad and almost straight sided, terminating internally in an obtuse point. The leaf texture was somewhat coriaceous and the tertiaries were camptodrome and of the usual Quercus type.

This species is based upon two specimens with their counterparts, the more perfect of which is figured, the other being slightly larger and showing the obtuse terminations of the lobes, supplying these parts which are missing in the figured specimen.

This is a rather handsome oak abundantly distinct from the forms heretofore known, and it is named in honor of Dr. Benjamin L. Miller who discovered the locality from which the collections were made.

Order URTICALES
Family *Ulmaceae*
Genus Planera J. F. Gmelin
PLANERA UNGERI Ettings

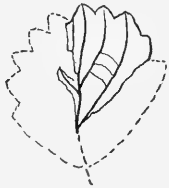

FIG. 4

Planera ungeri Ettings., Foss. Fl. v. Wien, 14. pl. 2. f. 5–18. 1851.
Heer, Fl. Tert. Helv., 2:60. pl. 80. 1856.
Fl. Foss. Arct., 2:472. pl. 45. f. 5a, c; pl. 46. f. 6, 7a, 1871.
Ibid., 5. ab. 6:53. pl. 15. f. 19; ab. 7:40. pl. 9. f. 10; pl. 10. f. 1, 2. 1878
Ibid., 7:94. pl. 75. f. 11; pl. 89. f. 9; pl. 92. f. 9; pl. 95. f. 6. 7; pl. 97. f. 3. 1883.
Kovats, Foss. Fl. v. Erdöbénye, 27. pl. 5. f. 1, 2; pl. 6. f. 1–6. 1856.
Lesq., Tert. Fl., 190. pl. 27. f. 7. 1878.

Velenovsky, Fl. Ausgebr. Tert. Letten v. Vrsovic, 26. pl. 3. f. 18–23; pl. 4. f. 14. 1882.
Friedrich, Beitr, Tertfl. Sachsen, 164. pl. 26. f. 2, 3. 1883.
Knowlton, Bull. U. S. Geol. Surv., No. 204:55. 1902.

Fragments of this ubiquitous species are fairly common at Richmond, the one figured being the most definite. It indicates a somewhat more orbicular leaf than the majority of leaves of this species but may be compared with several Greenland leaves which Heer identifies as *Planera ungeri.*[1] The marginal teeth and venation are identical with those of more complete specimens from European Tertiary localities and the implied environmental conditions were also most suitable. There is some resemblance to the Mascall species *Betula ? dayana* of Knowlton[2] and also to the Tortonian *Betula weissii* Heer[3] of Europe.

Planera ungeri has a recorded range from the Eocene into the Pleistocene and a distribution from Manchuria and Japan through Asia and Europe to Colorado and Oregon, occurring also in Greenland and Iceland. It is quite possible that more than one species may be included under this name but if such is the case their proper segregation is still a task for the future.

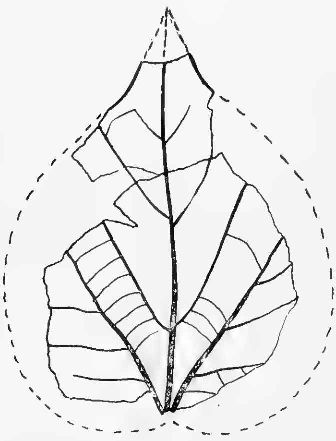

FIG. 5

Family *Moraceae*
Genus Ficus Linné
FICUS RICHMONDENSIS sp. nov.

Leaves apparently cordate in outline, about 5 to 6 cm. long by 5 cm. in greatest width, acuminate, entire. Venation palmate, the lateral primaries of somewhat less caliber than the midrib, from which they diverge at an acute angle (about 30°) at or near its base. The midrib gives off three pairs of secondaries above the lateral primaries

[1] Cf. Heer, Fl. Foss. Arct., 7. pl. 89. f. 9; pl. 95. f. 7. 1883.
[2] Knowlton, U. S. Geol. Surv., *Bull. No. 204,* 41, pl. 4, f. 4, 1902.
[3] Heer, Fl. Tert. Helv., 2:39, pl. 71, f. 24, 1856.

and these are apparently camptodrome. Tertiaries numerous, but slightly curved, transverse. Lateral primaries giving off externally three or four nearly straight branches.

The fossils, like the recent species of Ficus, are very numerous and range from the Cretaceous upward. The present species is based on the single imperfect specimen figured, which seems to be referable to this genus although the allied genus Celtis suggested itself. A rather similar form from Florissant, Colorado, is doubtfully referred by Cockerell to the genus Morus.[1] The entire margin is a more constant character in Ficus than it is in either of these other genera and the venation is closer to that of the leaves usually referred to Ficus, which facts have largely determined the present identification.

Order ROSALES

Family *Platanaceae*

Genus Platanus Linné

PLATANUS ACEROIDES Goeppert?

Platanus aceroides Gœpp., Zeit. Deutsch. Geol. Gesell., 4:492. 1852.
Lesq., Am. Journ. Sci. (ii). 45:206. 1869.
Tert. Fl., 184. pl. 25. f. 4–6. 1878.
Proc. U. S. Natl. Mus., 11:19. pl. 5. f. 7. 1888.
Heer, Fl. Tert. Helv., 2:71. pl. 87. f. 1–11; pl. 88. f. 5–12, 15. 1856.
Fl. Foss. Arct., 1:111. pl. 12. f. 1–8; pl. 47. f. 3. 1868.
Knowlton, Bull. U. S. Geol. Surv. No. 204, 65. 1902.
Hollick, Md. Geol. Surv., Pli. & Pleist., 231. pl. 73; 74. 1906.

Two fragments of Platanus leaves showing neither the outline nor margin, but containing parts of two secondaries with the characteristic tertiary venation of this genus, were found at Richmond. Their specific affinity cannot be made out with certainty, and they are referred to this species with some hesitation. The tentative determination is made on the ground of the abundance of this species elsewhere at this time, and also immediately before and afterward. As far as the specimens will permit of comparison they agree perfectly with this form.

Family *Caesalpiniaceae*

Genus Podogonium Heer

PODOGONIUM? VIRGINIANUM sp. nov.

In the absence of the characteristic pods this generic reference can only be tentative. The species is based on a small rather thick leaflet,

[1] Cockerell, *Bull. Am. Mus. Nat. Hist.*, Vol. XXIV 1908, p. 88, pl. vii, fig. 19.

8 mm. in length by about 3 mm. in breadth, with a rounded-truncate apex and a somewhat narrowed acute base. Of the venation only the midrib is discernable.

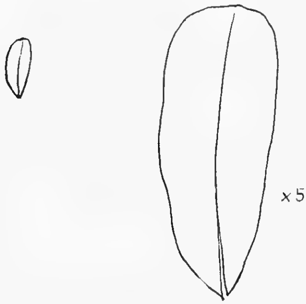

FIG. 6

The genus *Podogonium* is entirely extinct and is referred by Heer and others to the Caesalpiniaceae although Unger placed it in the Papilionaceae. In all there are about a dozen species, all Tertiary and ranging in age from the basal Eocene to the basal Pliocene (Messinian). It is chiefly European with but two species recorded from America. Five species have been found in the Tortonian of Europe.

Family *Papilionaceae*

Genus Dalbergia Linné f.

DALBERGIA CALVERTENSIS sp. nov.


FIG. 7

Leaflets small, 8 mm. long by 4.5 mm. in greatest width, which is toward the apex, obovate in outline with an emarginate to retuse apex and gradually narrowed acute base. Secondaries three pairs, opposite, ascending, camptodrome.

There are upward of eighty species of *Dalbergia* in the modern flora ranging through the tropics of both the old and the new worlds. The genus is abundantly represented during the Mid-Cretaceous by five or more species in Greenland and on the North American mainland. In Europe it is rather common during the Tertiary, Heer describing no less than four species from the Tortonian. There are also ten or a dozen species recorded from various European Oligocene localities.

Order SAPINDALES

Family *Celastraceae*

Genus Celastrus Linné

CELASTRUS BRUCKMANNI Al. Br.


FIG. 8

Celastrus bruckmanni Al. Br., in Stizenb. Verzeich., 87. 1851.
Heer, Fl. Tert. Helv., 3:69. pl. 171. f. 27–38. 1859.
Fl. Foss. Arct., 6. ab. 1:14. pl. 6. f. 5. 1880.
Ibid., 7:130. pl. 84. f. 9. 1883.
Gaudin, Contrib., 6:22. pl. 3. f. 6. 1862.
Rhamnus parvifolius Web., Palaeont., 4:154. pl. 27. f. 16. 1855.

This nearly complete elliptical leaf closely resembles the leaves usually referred to this species, although suggestive of the leaflets of a number of species of the Papilionaceae. It is about 1.6 cm. long by 1.2 cm. in greatest width, with four or five pairs of camptodrome secondaries.

Celastrus bruckmanni was recorded originally from the Tortonian of Baden and has since been found at a number of European localities, some ranging as low as the Aquitanian. It is recorded by Heer (*loc. cit.*) from the Greenland Tertiary, but has not heretofore been found on the North American mainland.

Family *Anacardiaceae*
Genus Rhus Linné
RHUS MILLERI Hollick

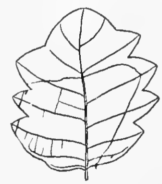

FIG. 9

Rhus milleri Hollick, Md. Geol. Surv., Miocene, 485. f. 1c, d. 1904.

This species which was described by Hollick a few years ago from the Calvert formation of the District of Columbia is represented by fragmentary specimens in the Richmond material.

In some respects these leaves suggest a relationship with *Myrica*, but the available material is so scanty that it is not desirable to make any change in the nomenclature. The missing parts in the figure have been restored from the more complete Maryland material, the outline of the Virginia specimen being indicated.

FIG. 10

Order UMBELLALES
Family *Cornaceae*
Genus Nyssa Linné
NYSSA GRACILIS sp. nov.

This species is based on a lanceolate, somewhat two-sided terete stone with about fifteen very narrow longitudinal ridges, possibly the remnants of slender wings. Length 8 mm., greatest diameter 2.5 mm., about equally pointed at both ends. The existing species of Nyssa number less than a dozen, inhabiting the warm temperate region of eastern North America and eastern and central Asia. A great many fossil species, founded chiefly upon stones, have been described, Perkins alone describing no less than eighteen species, an

altogether too large a number, from the Tertiary lignites of Brandon, Vermont. Leaves of two supposed species have been described from the Dakota Group and leaves and stones have been recorded from a large number of European localities, chiefly of Oligocene and Miocene ages.

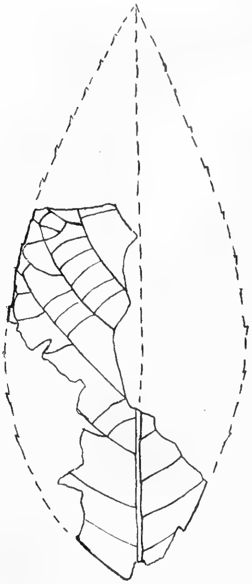

FIG. 11

Order GENTIANALES
Family *Oleaceae*
Genus Fraxinus Linné
FRAXINUS RICHMONDENSIS sp. nov.

Leaflets ovate in outline with a somewhat acuminate (?) apex and a rather rounded acute base, about 8 cm. long by 3.25 cm. in greatest width. Margin with very small remote serrate teeth. Secondaries ten or twelve pairs branching from the midrib at angles ranging from 65° for the basal pair to 40° for those in the apical part of the leaf, curving slightly upward, parallel, their tips joined by rounded festoons with the adjacent secondaries and sending off short curved branches to the marginal teeth. Balance of the tertiaries straight, transverse.

This species is based on the incomplete leaflet figured and its counterpart, and resembles both in size and outline the leaflets of the existing white (*Fraxinus americana* Linné) and red ash (*Fraxinus pennsylvanica* Marsh).

EROSIONAL ORIGIN OF THE GREAT BASIN RANGES

CHARLES R. KEYES

It is not at all probable that the origin of the mountain ranges of the Great Basin of western America can find adequate and satisfactory explanation by a single simple hypothesis. Nor can it be advantageously postulated that the genesis of the mountains is the same in the various parts of that vaster desert region of which the Great Basin is only a minor portion. In general all recent observations go to show that these mountains as they exist today must be regarded as the outcome of the action of several sorts of geologic forces, operating sometimes severally and sometimes in conjunction, at diverse times and with different degrees of intensity.

The relative ascendency of the several geologic processes in shaping the larger relief features of the desert region has remained until recently an indeterminate quantity. It is this aspect of the subject that has been all but entirely overlooked. This neglect has led to very divergent opinions, as is shown by a full dozen of distinct hypotheses advanced to explain the origin of the Basin ranges.

In the consideration of the origin of the American desert mountains, it is usually assumed that they are strictly structural features. That they may have been fashioned, partly at least, by other means is a suggestion which is only beginning to attract the attention which it merits. Present indications are that erosion—eolian erosion—must be reckoned with as one of the potent factors in desert sculpturing.

Many descriptions of the Great Basin ranges have been published. Notwithstanding this fact there has not yet appeared, as Davis[1] well says, "any detailed statement of the theory by which they are explained; the essential consequences of the theory have not been explicitly formulated; the criteria by which a fault-block mountain may be recognized in early or later stages of dissection have not been defined."

[1] *Bull. Mus. Comp. Zoöl.*, XLII, p. 112, 1903.

Spurr[1] appears to be the first to bring into serious question the early explanation of Gilbert's, afterward adopted by King, Powell, Russell, and others,[2] regarding the simple fault-block origin of the Basin ranges. This author considers stream-corrasion as the most important or only sculpturing agency, but he expresses the opinion that erosion and upheaval have gone on together, more or less uninterruptedly ever since Jurassic times, the mountains being eroded from a folded substructure in the same way as in the case of the Appalachians, when the precipitation was much greater than at present, while "subsequently the climate became arid and the water-supply was not sufficient to remove the detritus from the valleys, which filled up." This view, however, as will be seen later, does not appear, according to Davis,[3] to be sufficiently supported.

The idea of the Basin ranges presented by Davis[4] recently is that they are "dissected fault-block mountains." The descriptions, and illustrations which accompany them, indicate clearly that the mountains are regarded as blocks first upheaved and tilted and then subjected to rapid corrasion by the mountain torrents, the intermont areas being deeply filled by the rock-waste of the contiguous highlands. This is practically Gilbert's hypothesis theoretically considered in its essential consequences, accompanied by the definition of some of the criteria by which the stages of dissection of a fault-block mountain may be recognized.

The Great Basin taken alone presents many difficulties to a clear interpretation of some of its most characteristic features. Farther south in the desert region, at the northern end of the Mexican tableland, there are displayed certain phenomena which seem to offer critical evidences bearing upon the question in hand. A few years ago I incidentally referred[5] to the probable significance of some of these features and to the physiographic evolution of that part of the country, regarding the region as a peneplain that had been uplifted in mid-Tertiary times, broken into high blocks, and then subjected to

[1] *Bull. Geol. Soc. America*, XII, p. 217, 1901.

[2] *Geog. and Geol. Expl. and Surv.* W. 100 Merid., Prog. Rept., p. 48, 1874.

[3] *Science*, N. S., XIV, p. 457, 1901.

[4] *Bull. Mus. Comp. Zoöl.*, XLII, p. 131, 1903.

[5] *American Geologist*, XXXIII, p. 22, 1904.

vigorous erosion, the effects of the latter being fully as important as the faulting in producing the present relief expression. Being fresh from the humid regions all denuding agents spelled water-action.

All of the above allusions to the erosional agencies in the desert ranges of the West have referred solely to the work of water. Of the possibility of the existence of any other effective denuding power there has been small hint. Only very recently have other erosive influences been suggested to account for some of the most conspicuous of the desert features. It now seems probable that wind-scour must be regarded as the chief erosive power in the dry regions.

In the Great Basin area the salient aspects of the country are quite different from the larger relief features of other parts of the western desert region. There is some of the faulting that is more recent and more profound than elsewhere. Late orogenic movements are perhaps more extensive. Evidences of much greater precipitation than now at no distant geologic date are manifest. No noteworthy streams traverse the district to disguise the effects of typical desert-leveling. Little is yet known in regard to the probable nature of the surface relief prior to the commencement of the present arid period. The general conditions are such as to present little critical evidence in support of any hypothesis yet proposed concerning the genesis of the desert ranges.

In other portions of the desert region far to the south and southeast of the Great Basin, in Arizona, New Mexico, and Old Mexico, there are many features suggestive of structures and conditions which formerly prevailed but of which there is small hint to be derived in the more northern area. The most noteworthy of these characteristics are the mesas, or plateau-plains, many of which now stand high above the present level of the intermont plains, or general plains-surface of the region. These mesas manifestly represent, as recently shown,[1] former positions of the general plains-surface. Their greater resistance to erosional influences and the general lowering of the region is due mainly to the protection afforded by extensive lava-flows which are now the capping-rock of the remnantal levels. The surfaces on which the lavas rest are true beveled rock-floors, just as in the cases of the present plains.

[1] *Bull. Geol. Soc. America*, XIX, p. 63, 1908.

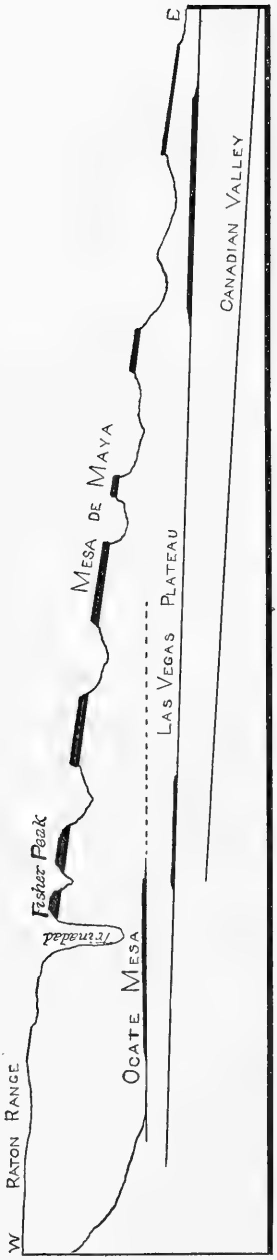

FIG. 1.—Substructure of the Mesa de Maya Plateau; New Mexico.

The most remarkable of these elevated plains is the Mesa de Maya, in northeastern New Mexico. Its extension is the flat crest of the Raton Range. The greater part of the mesa is formed by a thick basalt plate, 500 feet in thickness, resting on the beveled edges of soft Laramie shales and sandstones. This mesa is gently inclined to the eastward and extends from the Rocky Mountains a distance of more than one hundred miles to beyond the Texas line. (See fig. 1). It is 3,500 feet above the next extensive plains-level below, known as the Ocate mesa, which in turn is 500 feet above the general plains-surface of the region, or the Las Vegas plateau. It appears that the Mesa de Maya represents practically a Tertiary peneplain which existed at the time of the general elevation of the region. At the town of Raton its surface is now 9,000 feet above tidewater. Were it not for the great lava-field the remnants of which constitute this plateau-plain there would today remain no undoubted traces of the old peneplain in this part of the country.[1]

That the Mesa de Maya is the remnant of what is essentially a peneplanation-level which, perhaps, once extended over much, if not most, of the present desert region around the southern end of the Rocky cordillera, is strongly supported by a number of facts: (1) The foundation strata, both hard

[1] *Proc. Iowa Acad. Sci.*, XV, p. 221, 1908.

and soft, which alternate frequently, are evenly beveled, indicating that the country at the time of planation must have been only slightly above the sea-level. (2) The principal orogenic deformation and faulting appears to have taken place in early or mid-Tertiary times, and prior to the period of the general planning-off of the country, as represented by the Mesa de Maya level. (3) The numerous mountain ranges of New Mexico, outside of the Rockies, are subequal in height, a fact, when taking into account the period of the principal deformation and faulting, the general alternation of hard and soft belts of rock, and the extent of the subsequent denudation, showing that the present cycle of erosion must have started with the country already more or less of a plain. (4) The present bilateral symmetry of most of the desert ranges, even in the cases of the so-called tilled block-mountains, as the Jemez, Sandia, Franklin, Magdalena, and Caballos ranges, for examples, is suggestive of long-continued attack by the elements upon the hard mountain rock. In each of the mountains mentioned the major fault-line, if it really exists, is as far from the crest of the mountain-ridge as is the foot of the backslope. (5) Plateau plains that lie high above the present general plains-surface, but still far below the Mesa de Maya level, are beveled rock-surfaces, protected usually by lava flows. (6) With all of the present ranges of the so-called block-type bordered on either side by soft beds of great thickness, and the very resistant mountain strata, in monoclinal attitude, once extending such relatively long distances beyond the present mountain crests, it does not seem likely that general lowering of the surface of the country could have gone on so evenly without something of a plains-surface to begin with. (7) The postulation of a general mountainous surface at the commencement of the present geographic cycle as represented by the Mesa de Maya planation surface finds many incongruities which need not be dwelled upon at this time.

How utterly inadequate is any purely tectonic explanation of the larger relief features of the Western desert region, as they today exist, becomes readily apparent so soon as the real nature and the physiographic significance of certain of these characteristics are taken into account. In the consideration of erosional effects in the desert there are some important pecularities which are commonly overlooked.

The principles of water-action in the normal humid lands are applied with the only reservation that there is somewhat less water involved. No distinction is made between the efficiency of water-action on the plain and in the mountain. On the plains, with the exception of the local and sporadic flood-sheet, the general effect of water as a corrading agent is practically *nil*. A very large part of what rainfall occurs on the plains sinks at once into the ground. On the mountains where the general erosion effects have been chiefly observed the results are not so very unlike what they are in the humid regions generally.

By all those who, with the idea of genesis in mind, have recently traversed the region, it is conceded that erosion has had much to do with giving to the desert country its present topographic expression. That the erosion is not chiefly water-erosion but mainly eolian in character is an aspect of the subject which has received but scant attention. The potency of wind-scour as an erosive agent under conditions of dry climate is amply shown in many ways, and to an extent heretofore unsuspected. Its grander effects as compared with those of water corrasion are quite distinctive. Among them none is more characteristic than the beveled rock-floor which the intermont plains of the arid region present, as fully described in detail in another place.[1] Its real significance as indicating that these plains are areas of marked degradation instead of aggredation, as commonly supposed, is here especially pointed out. The vastness and evenness of the intermont plains have no known counterpart among the plains of the humid regions. Desert plains are smoother than peneplains possibly can be, as Passarge has stated. The singular isolation of the desert ranges, for they are usually completely encompassed by plains as by the sea, the entire absence of foothills, the plains-character of the rock-floor itself,[2] the representation of former plains-levels by the plateau-plains, the remarkable thinness of the surface mantle of débris, the total absence of distinct water-ways on the plains,[3] the notable independence of, and marked differences in, level of contiguous plains, and the general tectonic characters,[4] are inex-

[1] *Am. Jour. Sci.* (4), XV, p. 207, 1903; also *Bull. Geol. Soc. America*, XIX, p. 86, 1908.

[2] *Eng. and Min. Jour.*, LXVIII, p. 670, 1904.

[3] *American Geologist*, XXXIV, p. 160, 1904.

[4] *U. S. Geol. Sur.*, Water Sup. Pap. No. 123, 1905.

plicable by any method of water-sculpturing. They are all readily accounted for, however, through eolian activities under conditions of an arid climate.

The close tectonic pattern of the American desert region has done much to obscure the real significance of its most striking features. In South Africa, where the great elevated plateau of the dry region has been long relatively free from orogenic movement, there are the same isolated mountains, the same vast and even intermont plains, and the same streamless country. In that region the vigor of wind-scour action and the impotency of water corrasion is amply attested by the recent observations of Passarge,[1] and others. In the Great Basin the wind as a factor in general erosion appears not less effective. It seems probable that we must now regard wind-scour not only the most important erosive agent under conditions of aridity but more potent than all other agencies combined. Moreover, in the production of the present desert mountains its influence doubtless very far surpasses that of any recent deformation or dislocation.

From a view-point of true desert conditions all late observations in the arid country of southwestern United States go to show: (1) That there existed at the beginning of the present geographic cycle a broad peneplain at a level of about 4,000 feet above the present plains-surface; (2) that the major faulting and gentle folding of the region took place chiefly before the beginning of the present cycle; (3) that water-action is unimportant; (4) that wind-scour is very potent; (5) that the belts of hard and soft strata produced by the deformation in former cyles allowed the winds to erode the latter much more rapidly than the former, producing the present plains, and leaving many of the former as monadnock ranges; and (6) that while differential movements of the rock-masses have in all likelihood taken place recently and locally their direct effects compared with those of eolian erosion have been relatively unimportant in the formation of the present orographic expression of the desert country; and (7) that, all things considered, the comparative values of deflation and corrasion in the arid regions may be expressed by the estimate that the volume of rock-waste brought down by the waters from the mountains in a year may be removed by the winds in a single day.

[1] *Zeitsch. d. deutschen geol. Gesellschaft,* LVI Bd., Protokol, pp. 193–209, 1904.

A CONTRIBUTION TO A MONOGRAPH OF THE EXTINCT AMPHIBIA OF NORTH AMERICA. NEW FORMS FROM THE CARBONIFEROUS

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In the course of an extended investigation of the extinct Amphibia of North America the writer has studied several forms from the Carboniferous which cannot be referred to any known species and they are here described as new. He has, so far, studied thirty-five species of the Carboniferous Amphibia of North America, all of which, with one or two exceptions, belong to the Branchiosauria and Microsauria. The Branchiosauria are represented by a single species. Of the Microsauria there has been an abundance of material available, thanks to the kind offices of Dr. Bashford Dean and Dr. Louis Hussakof of the American Museum, who very generously gave the writer the privilege of examining nearly a hundred of the specimens studied by Cope. There are already prepared some two hundred pages of manuscript and nearly sixty drawings toward the completion of a monograph of the extinct Amphibia of North America, but as the publication of this must be deferred until the remainder of the known North American and the European species have been studied, it is thought advisable to describe the following forms in advance, the more detailed treatment of the described forms being held for the monograph.

The extinct Amphibia of the North American Paleozoic present a variety of forms, of very diverse organization. The forms known range from very small creatures like *Micrerpeton caudatum*, less than two inches in length, to large forms like *Eryops megacephalus* Cope from the Permian of Texas, which probably attained a length of eight or ten feet. A rather interesting parallel can be drawn between the Paleozoic Amphibia and the reptiles of today. The snakes are represented in the Paleozoic by the limbless, snake-like Amphibia, such as *Ptyonius*, *Dolichosoma*, *Ophiderpeton* and *Molgophis* of North

America and Europe. The lizards find their counterpart in the Hylonomidae and the Tuditanidae. The turtles are represented by *Dissorophus* and its allies from the Texas Permian and the crocodilian aspect of the fauna is found in the large labyrinthodonts of the Permian, but more especially of the Triassic.

The Amphibia whose remains are found preserved in the Carboniferous rocks of North America all belong to the order Stegocephala, characterized by the completely roofed-over cranium and the great development of the parasphenoid. Five suborders of the Stegocephala may be recognized. These are: The Branchiosauria, The Microsauria, The Aistopoda, The Temnospondyli, and The Stereospondyli. All five of these suborders are represented in the Carboniferous of North America but it is our purpose here to examine only forms belonging to the first two suborders, i.e., the Branchiosauria and the Microsauria.

The Branchiosauria were salamander-like in form and were, for the most part, devoid of the heavy dermal armor of many of their contemporaries. They were naked, with the exception of small ovoid scales on the back and the chevron-shaped armature of the ventral surface which was almost universally present among the Carboniferous Stegocephala and may have been present in the Amphibia as late as the Laramie Cretaceous. The tail was rather long and flattened from side to side and the creatures were adapted for life in the water for at least the early part of their existence, as is shown by the possession of gills in many of the Permian and late Carboniferous forms of Europe. The group of the Branchiosauria are without doubt the direct ancestors of the modern salamanders and perhaps of the other groups as well. No branchiosaurian has ever been described from so low in the geological series as the one here given and it is the first evidence of the occurrence in North America of a group which was so abundant in Europe during the Permian.

Micrerpeton caudatum gen. et sp. nov.

(Figs. 1–7)

The genus *Micrerpeton*, of which the single species is described below, is the only evidence of the occurrence of the Branchiosauria in North America, and as such is of unusual interest. There have

been three other genera referred to the Branchiosauria from the North American deposits but there is good evidence that none of them belongs here. The genus *Amphibamus* (Fig. 24) was originally referred to the Xenorhachia by Cope[1] on account of the supposed cartilaginous condition of the vertebrae and the absence of ribs. Later he abandoned this order and placed the form in the order Branchiosauria where it is retained by Zittel.[2] Recently Hay[3] has shown, and I am able to corroborate his statement, that there are ribs present in the species *Amphibamus grandiceps* Cope, and that they are long and curved, not at all like the short ribs of the true Branchiosauria. These long, curved ribs unquestionably exclude the form from the Branchiosauria and indicate its close affinites with the Microsauria. The genus *Pelion* has also been referred to this group on purely negative evidence.[4] The genus is excluded from the Branchiosauria by the well-ossified condition of the limb bones, in which the endochondral ossification is seen to be well developed, a condition which never prevailed among the Branchiosauria so far as is known. The form of the head and the elongated hind limb would also tend to exclude this form from the group. In the Branchiosauria the fore limb is usually larger than the hind limb, but in *Pelion lyelli* Wyman the hind limb greatly exceeds the fore limb in length. The genus *Sparadus* as it occurs in North America has also been referred to this group by Lambe.[5] In the first place the presence of the genus *Sparodus* in the deposits of North America is so uncertain as to render consideration of the form almost unnecessary. The presence of the genus is indicated by remains which are almost impossible of definition and such a reference as made by Dawson is at the best an uncertain one.

The form, *Micrerpeton caudatum*, is represented by very complete remains (Pal. Coll., U. of C., No. 12,313). The specimen is preserved on opposite halves of a nodule from the Mazon Creek beds of Grundy County, Illinois. In a recent conference with Dr. David White

[1] *Proc. Acad. Natl. Sci. Phila.*, 1865, pp. 134–37.

[2] Zittel, *Handbuch der Paleon.*, 1 Abth., Bd. 3, p. 375.

[3] *Proc. Amer. Phil. Soc.*, 1900, p. 120.

[4] Zittel, *Handbuch der Paleon.*, 1 Abth., Bd. 3, p. 375.

[5] *Trans. Roy. Soc. Canada*, 1904–5, Vol. X, p. 45.

he stated that the Mazon Creek beds are possibly to be placed somewhat lower than the Lower Kitanning, so that the deposits are in the lower part of the Allegheny series as they are now understood. The specimen was collected many years ago by Mr. W. F. E. Gurley at Mazon Creek but it has never been studied, although Dr. Newberry examined it and pronounced it to be amphibian and said in a note that Professor Cope should see it. Unfortunately Cope did not see it and it has lain unknown in the collection as unnoticed by students as if it were still in its old bed. I am indebted to Dr. Stuart Weller for calling my attention to the specimen and to him is due the interest which I have taken in the form.

The specimen (Fig. 1) is exceptionally perfect. Not only are nearly all of the skeletal elements present but the general contour of the body, the character of the dermal covering, the color-markings, the lateral line system, and many other features of interest have been detected. Such completeness of preservation is very uncommon even among the remains obtained from this locality. In this case the entire form was preserved but the collector in cracking the nodule lost the chips containing the hands and feet so that portions only of the limbs remain. It is thus impossible to determine the phalangeal formula, but the feet were probably like those of *Branchiosaurus amblystomus* Cred., as given by Credner, to which the present form is closely allied and indeed must be placed in the same family with *Branchiosaurus*, *Pelosaurus*, and *Melanerpeton*.

The remains here described represent a small salamander-like form, and they are the earliest geological evidence of the group, which without doubt gave rise to the modern salamanders. The parts preserved in the specimen are: the complete outline of the head with the cranial elements easily distinguishable and the black pigment of the iris; the entire vertebral column including pits in the tail region where the vertebrae were without doubt entirely cartilaginous; parts of the pectoral girdle; parts of the pelvic girdle; the humerus of the left side; the ventral scutellation; the ribs of one side of the body; and indications of ribs on the other; portions of both hind limbs and a complete impression of the fleshy tail. On this impression of the tail are preserved small horny scales, transverse color-markings, and distinct impressions of the lateral line system.

The bones of *Micrerpeton*, as in so many of the fossils from this locality, have been replaced by a white friable mineral which is

FIG. 1

FIG. 2

FIG. 1.—Impression of *Micrerpeton caudatum* on the Mazon Creek nodule. The median lateral line is distinct and evidences of the ventral scutellation may be seen on the upper side of the vertebral column. Two and one-third times natural size.

FIG. 2.—A photograph of the ventral scutellation of *Micrerpeton*. $\times 5$.

probably kaolin. The animal is preserved on its back and the photograph (Fig. 1) represents the ventral surface of the form. The entire length of the animal is only 49 mm of which the tail occupies nearly one-half.

The head has much the same shape as in the species of *Branchiosaurus*, figured by Fritsch and Credner. The eyes occupy relatively the same position as in that genus. The orbits are very large and are broadly oval. Within the borders of the rim the stone is blackened as though by the black pigment of the iris such as Cope has described in *Amphibamus*.[1] Under a rather high power of magnification the cranial bones are seen to be represented by mere flakes of white mineral matter. The sutures separating the cranial elements are distinctly preserved on the obverse of the main nodule and the description of the elements will be as they are there depicted.

The openings of the skull are five: the two orbits, the two minute nostrils and the pineal foramen. A median suture separates the skull into two equal halves and the pineal foramen lies slightly anterior to the posterior third of its length. The boundaries of the premaxillae are not distinct but they were very small elements and formed the inner border of the nostrils which are clearly indicated by bosses of stone. The nasal element is nearly square and lies anterior to the frontal which it borders broadly. The parietal is about the same size as the frontal and it apparently forms a portion of the inner border of the orbit although this is not an assured character. The parietal is elongate and unites posteriorly with the supraoccipital. The supraoccipital with the epiotic and the supratemporal (prosquamosal) form the posterior boundary of the skull and they are hence not unlike the same elements in other Stegocephala. The prefrontal forms the anterior border of the orbit. The lachrymal has not been detected. The maxilla is elongate and forms the antero-lateral border of the skull. No teeth nor impressions of teeth have been detected. The maxilla is elongate and forms the antero-lateral border of the cranium. The jugal forms an important element in the lateral border of the cranium and joins the quadratojugal posteriorly. The postfrontal is triangular and with the postorbital forms the posterior border of the orbit. Both of the elements are acuminate posteriorly although the

[1] *Proc. Acad. Natl. Sci. Phil.* 1865. p. 137.

suture between them is indistinct. They inclose between their posterior acuminations an interior projection of the squamosal. The squamosal has the usual relations and borders the supratemporal laterally. The latter element forms the quadrate angle of the cranium.

The entire length of the vertebral column is preserved although the nature and structure of its elements cannot be determined. The impressions of a few of the vertebrae show that some of the centra were amphicoelous but other than this nothing can be stated. The cavities which the centra occupied were filled by the white mineral matter and the force of the blow which cracked the nodule destroyed the form of the mold. It is possible that where the mineral matter has filled the cavities the centra were bony or partly so and where the cavities were unfilled the centra were entirely cartilaginous. The length of the vertebral column from the base of the skull to the last impression of a cartilaginous centrum is 33 mm.

The number of centra between the sacral vertebra and the skull is twenty (Fig. 5) as they are preserved but there may have been one more, the atlas. Fritsch has represented twenty-one in his restoration of *Branchiosaurus salamandroides* and this is further indication of an affinity between the two genera although Credner has represented twenty-six presacral vertebrae in *Branchiosaurus amblystomus.* The presacral vertebrae are thus seen to vary within narrow limits, but the number of presacrals is near twenty and this may be taken as typical. It is interesting to notice that in modern forms of the salamanders the presacral vertebrae are about twenty. The significance of this will be discussed elsewhere. There is but a single sacral centrum in *Micrerpeton.* The sacral rib has not been detected but it is restored after the condition given in *Branchiosaurus.* The right femur partially covers the sacral vertebra. Its structure cannot be determined. I count impressions of seventeen caudal centra of which at least twelve may have been partially ossified. In the cervical region there are distinct impressions of transverse processes on at least five vertebrae and this number is assigned to the neck although it is by no means certain that this is the correct number. The neck was at least short if we may judge from the position of the remains of the pectoral girdle. No cervical ribs are definitely determined. There is a short

rib lying between the fifth and sixth vertebrae but to which it belongs is uncertain.

There are impressions of ten ribs preserved on one side of the vertebral column and one on the other side. They are short, straight, and heavy as are the same elements in *Branchiosaurus*. This character alone is sufficient to place *Micrerpeton* among the Branchiosauria since no such ribs are known in other groups of the Stegocephala. The ribs preserved lie next the seventh to the seventeenth vertebrae on the left side and there is one on the right side which may belong to either the fifth or sixth vertebra. The ribs are central in their attachment and in this they agree well with the mode of rib attachment of the ribs in modern salamanders. All of the ribs are single headed and are composed, for the most part, of perichondral tissue. The position of the ribs in the matrix, inclined backwards and making a small angle with the vertebral column is very suggestive of the condition found in *Branchiosaurus*.

The pectoral girdle is represented by three distinct elements of the left side. They are identified as scapula, clavicle, and coracoid. This is the nomenclature given by Woodward although Credner would call them otherwise. The nomenclature and morphology of the elements of the pectoral girdle will be discussed fully elsewhere and is not necessary here. The scapula is represented by an ovoid fragment lying next to the vertebral column. The clavicle was probably spatulate as it is in *Melanerpeton* but the inner end of the element is not visible. The coracoid is represented by its outer end only and its inner pointed extremity is not visible. The interclavicle has not been detected.

The humerus lies somewhat to one side of the pectoral girdle as if there had been a large amount of articular cartilage. Its position may be due to post-mortem shifting but there is little other evidence of any movement after deposition. The humerus is a large heavy bone in comparison to the rest of the skeleton. It is expanded at each end and its ends show concavities proving that the bone is formed principally of perichondral tissue as would be expected from such an early Branchiosaurian. The endochondrium has not yet developed in this form which is evidently adult. There is no other element of the arm present.

Of the pelvis there is but a single element present. This is a slender elongate rod and it is undoubtedly the ilium since it has the usual position for that element and is much too large for a sacral rib. It has much the same shape as in the modern *Salamandra*. It is not expanded as in the ilium of *Branchiosaurus*. This element, like the humerus, seems to have been but a hollow cylinder of bone and undoubtedly had cartilaginous ends as in the ilium of the recent *Salamandra*.

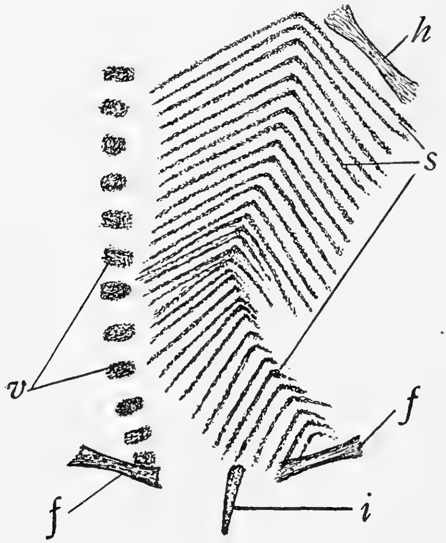

FIG. 3.—Ventral scutellation of *Micrerpeton caudatum*. F = femur; H = humerus; I = ilium; S = the lines of scutes; V = the vertebral column. ×5.

The two femora are preserved nearly entire. The right one lies upon and partly obscures the sacral vertebra. The femur is much more slender than is the humerus. It is but slightly expanded at the ends and like the humerus shows the concavities at the ends indicative of the perichondral character of the tissue composing it. The endochondral tissue is a later development and finds its first expression late in the embryonic and phylogenetic development of the vertebrates. Of the leg there are two elements preserved more or less entire (Fig. 5). These are the tibia and the fibula. The larger one may represent the tibia and the smaller one the fibula. They both present characters similar to those of the femur and the humerus. They are both rods of bone tapering at the distal end. The feet have been lost, though doubtless at one time present.

The ventral surface of the body, as in other members of the Branchiosauria, was covered and protected by a series of small scutes arranged in the regular chevron pattern (Figs. 2, 3). The form of the scutes and their number cannot be determined. The

lines which represent them are, however, distinct. A portion of the scutes are missing and part of them are obscured by lying over the vertebral column. They are all somewhat shifted to the left. The lines are very small and close together. I count sixteen of them in a distance of two millimeters. In length the longest line preserved is a little more than four millimeters, measuring from the point of the chevron. The lines representing the scutes came to a point in a median ridge which is now represented by a line. The dermal scutes on the abdomen were probably the forerunners of the abdominal ribs of the reptiles.

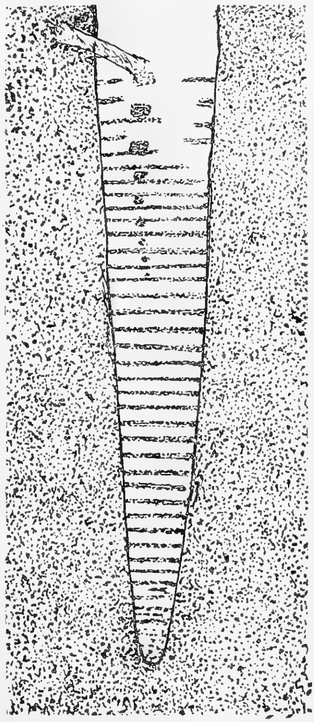

FIG. 4.—The banded color-markings on the tail of *Micrerpeton*. ×5.

The impression of the tail contains some of the most interesting features in the entire specimen. Scattered over it and in places laid in a mosaic are impressions of small dermal scales which may have covered the entire body. In form the scales are ovoid, being half as wide as long (Fig. 6). The markings on the scales partake of the nature of radiating lines much after the pattern of the sculpturing of the cranial bones in many of the Microsaurial and later forms. The scales are less than one-half a millimeter in diameter and their character can only be ascertained under high magnification. Near the middle part of the tail there are preserved distinct transverse bands of a dark color (Fig. 4). These markings are more or less evident throughout the entire tail impression but they are elsewhere not so distinct as in the central region. The lines are evidently due to rows of pigmented scales and in all probability the animal's entire body was transversely striped.

The most interesting and important single structure discovered on

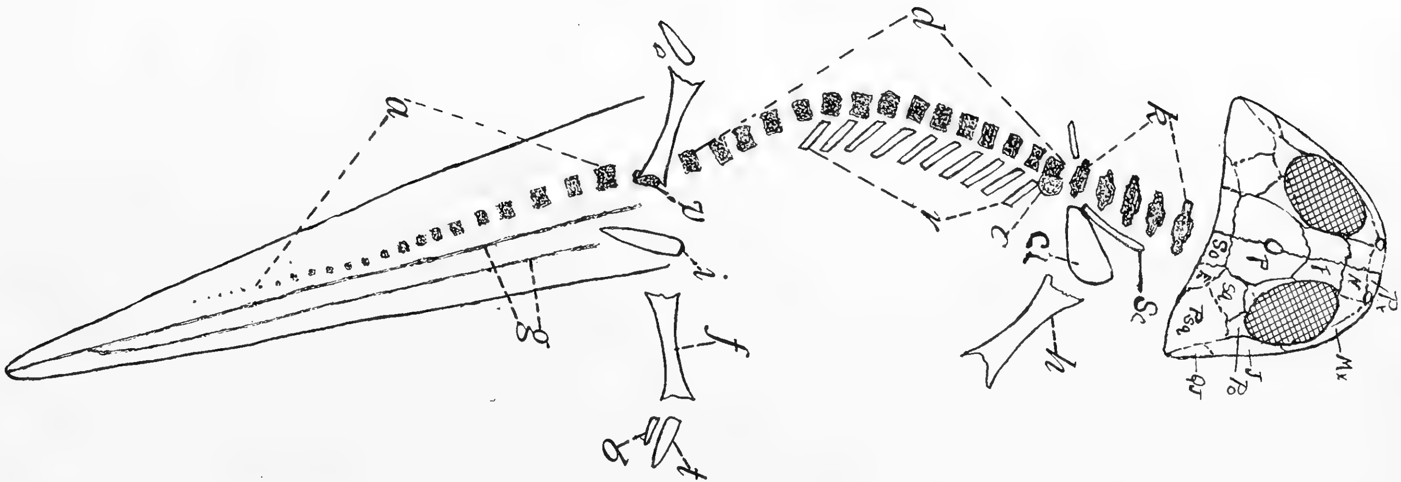

FIG. 5.—The skeletal elements of *Micrerpeton caudatum*, as preserved. E = epiotic; F = frontal; J = jugal; M = maxilla; N = nasal; P = parietal; Po = postorbital; Px = premaxilla; Qj = quadratojugal; Psq = supratemporal; So = supraoccipital; a = caudal vertebrae; b = fibula; sc = scapula; d = dorsal vertebrae; f = fibula; g = lateral line; h = humerus; i = ilium; k = cervical vertebrae; r = ribs; t = tibia; cl = clavicle; v = sacral vertebra; c = coracoid (?). ×5.

the specimen is the impression of the lateral line system, which is clearly evident as two dark lines on the impression of the fleshy part of the tail. The sense organs are represented by two longitudinal rows of pigmented scales, one beginning at the tip of the tail, the other

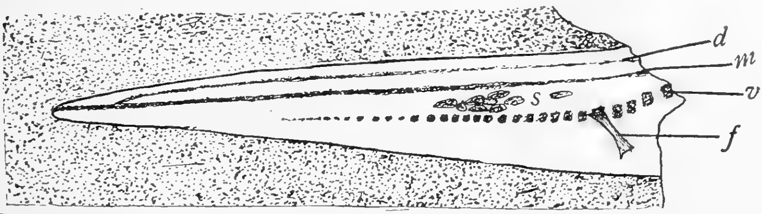

FIG. 6.—Impression of the tail of *Micrerpeton caudatum* showing the arrangement of the lateral line sense organs and the position of the vertebral column. D = dorsal lateral line; M = median lateral line; F = femur; S = scales; V = vertebral column. ×5.

taking its origin from the median line somewhat further forward. I am indebted to Dr. K. Takahashi for calling my attention to the similarity of this arrangement to that found in the modern *Necturus*. The arrangement and disposition of the lines containing the sense

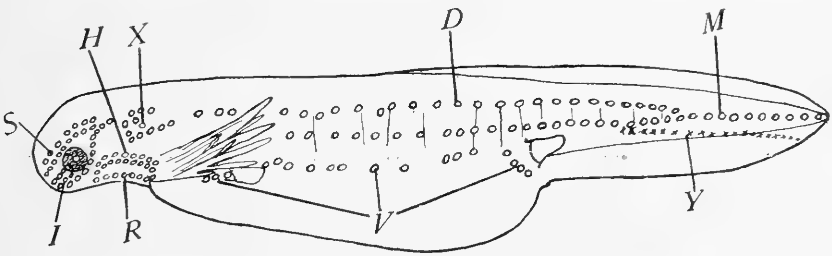

FIG. 7.—Outline of a young larva of *Necturus* showing the position of the lateral line system. D = dorsal lateral line; H = hyomandibular sense organs; I = infraorbital sense organs; M = median lateral line; R = mandibular sense organs; V = ventral lateral line; X = sense organs supplied by branches from the glossopharyngeal and vagus nerves; Y = the position of the vertebral column. Modified after Platt. Enlarged.

organs is practically the same in the two forms (Figs. 6, 7). The median lateral line takes its origin from the extreme tip of the tail and is continued to the base where the impression is broken. The dorsal lateral line has its origin rather abruptly from the median lateral line at a distance of six millimeters from the tip of the tail. The

sense organs were undoubtedly located beneath specialized pigmented scales on the surface of the animal's body and to this pigment is due the preservation of the lines.

The fact that the arrangement of the sense organs of *Micrerpeton* corresponds so exactly to the condition found in *Necturus* is of considerable interest. *Necturus* alone among the modern tailed Amphibia has the arrangement above described for the lateral line system in *Micrerpeton.* All other forms of the Caudata as also the larval forms of the Salientia have an arrangement of the lateral line system which is perfectly distinct from that found in *Necturus*, although the basal arrangement is the same in nearly all forms. In *Ambystoma*, for instance, the median lateral line is not present on the tail and the dorsal line is but incompletely developed. The close similarity of the arrangement of the systems of sense organs in the two forms, *Micrerpeton* and *Necturus*, may be of genetic significance with regard to the latter form. The lateral line sense organs are of a very fundamental significance and it is not at all improbable that the same arrangement of the lines has existed from the Carboniferous times down to the present. We know that such has been the case in a great many of the fishes. The ancestors of the modern Caudata must have originated somewhere in the Carboniferous or earlier periods and it is the opinion of the writer that the Branchiosauria represent the direct ancestral forms for this group of the modern Amphibia. This suggestion is by no means new, since Baur and others have held the same view. The writer hopes to present a fuller discussion of this topic at some future time.

-The relations of the form *Micrerpeton caudatum* are readily determined. The number of the presacral vertebrae, the form and position of the ribs, the shape of the skull, the arrangement of the cranial elements, the structure of the pectoral girdle, and the character of the ventral armature all clearly bespeak a close relationship with *Branchiosaurus*, *Melanerpeton*, and *Pelosaurus* from the Lower Permian and Upper Carboniferous of Europe. The distinction of the genus *Micrerpeton* from the other known branchiosaurian genera is found in the apparent absence of sclerotic plates, the shape of the skull, the arrangement of the cranial elements and the form of the ilium.

So far as I am aware the species above described is the earliest geological evidence of the Branchiosauria since the earliest forms known from Europe are from the Stephanian (Upper Carboniferous). The species is also the only true branchiosaurian known from North America as stated above. The presence of this form in America is of considerable interest in the bearing it has on the distribution and migration of the Paleozoic animals. It is a great distance from Europe where the other Branchiosauria are found, to America and it must have taken an immense length of time for such slow-moving creatures as the Amphibia to have migrated this distance. Whether the migration took place after the development of the branchiosaurian type or whether the type was evolved in the two places is an open question and must be settled by future research. It is possible that it was the piscian ancestors of the Amphibia which migrated across the seas and began the amphibian phase of their development independently in the two continents.

MEASUREMENTS OF THE SPECIMEN OF *Micrerpeton caudatum* MOODIE

	mm
Entire length of animal	49
Length of head in median line	6.5
Width of head at posterior border	8
Length of orbit	2.5
Width of orbit	2
Interorbital space	2
Length of vertebral column	33
Length of single vertebra in dorsal series	0.5
Length of trunk from base of skull to sacrum	22
Length of rib	1.5
Length of scapula	3
Width of clavicle, maximum	2
Length of humerus	2.5
Length of ilium	1.5
Length of femur	2
Length of tibia	1.5
Length of tail impression	21.5
Width of tail impression at base	4

The Microsauria are represented in the Carboniferous of North America by numerous forms usually with well-developed dermal plates and almost always with the ventral scutellation. They ranged

in size from the small *Tuditanus minimus* from the Cannelton slates of Pennsylvania, three or four inches in length, to forms like *Diplocaulus* and possibly *Macrerpeton* which without much doubt reached a length of several feet. All the members of this suborder had well-developed cranial elements which are usually ornamented with radiating grooves or with pits. The pectoral arch is well developed and is composed of dermal elements which are ornamented with sculpturing similar to that of the cranial bones. The body of these animals was in a few cases covered with overlapping scales, but others appear to have had only the ventral surface armed and this was in some cases especially strong as in the genera *Saurerpeton* and *Sauropleura*. The vertebrae are uniformly of the phyllospondylous type. This is so generally the case that the condition of the vertebrae is taken as one of the chief characters of the group. Various peculiarities are seen among the Microsauria in the development of horn-like projections on the skull in genera which are in no way genetically related. The Microsauria continued on into the Permian in the family Diplocaulidae.

The genus *Tuditanus* is represented by several species in the Carboniferous rocks of North America. Eight species are associated provisionally under this genus. Six of them were described by Cope from the Linton deposits of Ohio and two are described herewith from the Cannelton slates of Pennsylvania. A discussion of only three of the species will be given here since little of interest has been obtained from the study of the other species. The three forms here discussed are *Tuditanus tabulatus* Cope, *T. minimus* sp. nov., and *T. sculptilis* sp. nov. The facts which make the first-named species of interest here are the discovery of the lateral line canals on the skull and the correction of several errors in the original description as given by Cope.

Tuditanus tabulatus Cope.

(Figs. 8, 9)

The species is known from a single well-preserved skull and its obverse in the collection of the Columbia University of New York City. I am indebted to Dr. Bashford Dean for the privilege of studying this interesting form. It is from the Linton deposits of Ohio.

The remains include a nearly complete cranium and a complete clavicle of the right side. The species agrees in all essential respects with the characters of the genus *Tuditanus*, presenting a broad, flat head, and a triangular thoracic shield.

The cranium is wider than long and the muzzle is broadly rounded (Fig. 8). The orbits are wide ovals, and their posterior borders fall little behind the transverse line dividing the skull equally. The interorbital width equals the longitudinal diameter of the orbit. The posterior outline of the cranium is truncate in a straight transverse line between the prominent epiotic angles. The composition of the cranium is different from any of the other species referred to this genus in the large size of the epiotic and the fact that the squamosal is excluded from the parietal by the extension of the postorbitals and the epiotics. This may be a generic character and entitle the form to another name but it is retained here for the present. The elements of the anterior part of the skull are not preserved but they are indicated by the broken lines. The nostrils are, however, clearly indicated as bosses of shale. There is a mere fragment of the nasal preserved posterior to the crack indicated by the transverse line (Fig. 9). The frontal is elongate as in other species of the genus and forms the inner border of the orbit. The parietal, as usual, is one of the larger bones of the skull roof and the pineal foramen is inclosed in the median suture by the two parietal elements. The parietal opening lies in

Fig. 8.—The skull and right clavicle of *Tuditanus tabulatus* Cope. One and one-half times natural size.

the posterior half of the parietal. The supraoccipital is almost square being slightly elongate transversely. It unites laterally with the epiotics with which it forms the truncate table of the skull. The suture separating the epiotic from the squamosal is clearly distinct. Although such a position for the squamosal is unusual it is not unique since the same character has been observed in *Diceratosaurus laevis* to be described later. The postfrontal is rather small and it together with the postorbital forms the posterior boundary of the orbit. The postorbital is truncate posteriorly and joins the epiotic broadly. The squamosal lies posterior to the postorbital and jugal and borders the quadratojugal which is an unusual condition but what significance the condition has remains to be determined. Posterior to the squamosal lies the supratemporal which forms the quadrate angle of the cranium. The quadratojugal is a small element and forms a part of the lateral boundary of the skull. The jugal is a large element and forms the entire lateral border of the orbit. There are no teeth preserved on the fragment of a maxilla but there are some impressions farther forward which resemble the pleurodont denticles of the modern Amphibia.

The sculpture of the surface of the cranium consists of parallel ridges which are separated by grooves equal to them in width. The ridges radiate inward on the squamosals and frontals and outward on the supratemporals. They are somewhat interrupted on the other skull elements. The lateral thoracic shield, which represents the right clavicle, is ornamented with a similar sculpturing of uninterrupted radiating ridges. Cope described an atlas in connection with this skull but I do not find it. The slender impressions to the right of the pectoral shield may possibly represent ribs. They are gently curved and truncate at the inner end.

A nearly complete system of lateral line canals has been detected on this skull (Fig. 9). The canals preserved are: the temporal, the jugal, the infraorbital, the occipital cross-commissure and the supraorbital. The nomenclature of the canals is that adopted in a contribution on the sensory canals in the extinct Amphibia now in press. The occipital cross-commissure is represented by a row of elongate pits such as Andrews[1] has described for *Ceraterpeton galvani* Huxley

[1] *Geol. Mag.*, Dec. IV, Vol. II, p. 81.

from the Coal-measures of England. The cross-commissure is contained within the epiotics. The jugal and the temporal canals form a complete ring much as the same canals do in *Trematosaurus*. The squamosal in *T. tabulatus* is excluded from the parietal by the extension of the epiotic and the postorbital and it is to be noticed that the temporal canal has a changed position to correspond with the changed condition of the squamosal. This is of considerable interest in connection with the correlation of the squamosal in fishes and amphibians. This subject has been fully treated in another place, and it will only be necessary here to state that on the basis of the lateral line canals and their arrangement in the fishes and the Amphibia the true correlation of the squamosal element in amphibians and fishes has been made. This contradicts the results obtained by Thyng[1] from embryological studies. Thyng's results are noticed more fully in the paper above cited. The temporal canal has apparently an indication of a connection with the supraorbital canal but of this I am not sure. The jugal canal occurs on the supratemporal, quadratojugal, and it joins the infraorbital on the jugal. The infraorbital is indicated by a short portion some few millimeters long under the orbit and the rest, i.e., its connection with the jugal canal, is restored. There is nothing unusual to be observed in that portion of the infraorbital canal which is preserved. The supraorbital canal is indicated by a curved, broad, shallow groove on the inner side of each orbit. As above stated there seems to be a connection between this canal and the temporal but I am not sure. The primitive conditions shown in the lateral line canals in *T. tabulatus* are the presence of the occi-

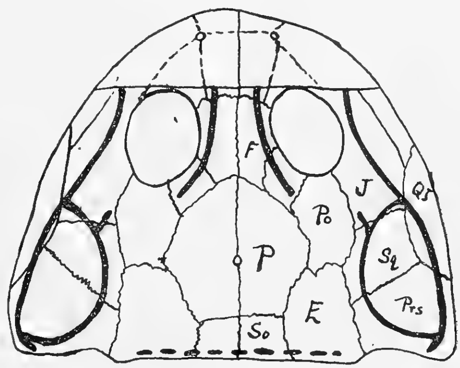

FIG. 9.—The outline of the cranial elements and the lateral line canals in *Tuditanus tabulatus* Cope. One and one-half times natural size.

[1] "*Tufts College Studies*," 1906, Vol. II, No. 2.

pital cross-commissure and the ring-like formation of the temporal and jugal canals which is too clearly indicated to be overlooked.

Measurements of the Type of *Tuditanus tabulatus* Cope

	mm
Median length of the skull	29
Width of skull at posterior border, estimated	37
Width between epiotic angles	18
Length of orbit	8
Width of orbit	6.5
Diameter of nostril less than	1
Diameter of pineal foramen less than	1
Length of right clavicle	13
Width of right clavicle	5.5

The specimen with its obverse representing this species is from Linton, Ohio. It formed a part of the collection of Dr. J. S. Newberry and is now in the Zoölogical Collection of Columbia University, New York City.

Tuditanus minimus sp. nov.

(Fig. 10)

The form represented by the above-named species is preserved on one side of a slab of slate, belly downward, from Cannelton, Pennsylvania. The obverse slab has been lost, which is very unfortunate, since there is no doubt that the entire skeleton was preserved. The species is placed in the genus *Tuditanus* on account of the close resemblance to the type form *T. punctulatus* Cope, although it is much smaller than that species. It is in fact the smallest of the Microsauria which the writer has thus far studied.

Tuditanus minimus, as the name implies, is not only the smallest member of the genus but of the suborder as well, as has just been stated. It did not attain a total length of more than three and one-half inches. Its form is very lizard-like but its structure is typically stegocephalan. The form of the skull is especially similar to that of the type species *T. punctulatus* which it resembles in the narrow posterior truncation of the skull, as well as in the anterior position of the orbits.

The skull is in the form of a narrow oval, sharply narrowed posteriorly and truncate. The orbits are located well forward and their

posterior border lies in front of the line dividing the skull transversely into equal parts. The interorbital space is greater than the diameter of the orbit. Impressions of teeth are preserved on the premaxillae and maxillae (Fig. 10). There are eight of them in a distance of three millimeters. The teeth appear to be mere blunt denticles and were possibly pleurodont.

The elements of the cranium are very poorly preserved. It has been impossible to determine all of the sutures. The bones of the premaxillary region have been destroyed but the arrangement of them was probably not far different from that which obtains in other members of the genus. The posterior boundaries of the nasals are preserved and prove this element to have had an obtuse posterior border. The sutures bounding the frontals are clear and show that they were small and that they formed a part of the inner boundary of the orbits. The parietal is recognized as a large element, apparently the largest in the

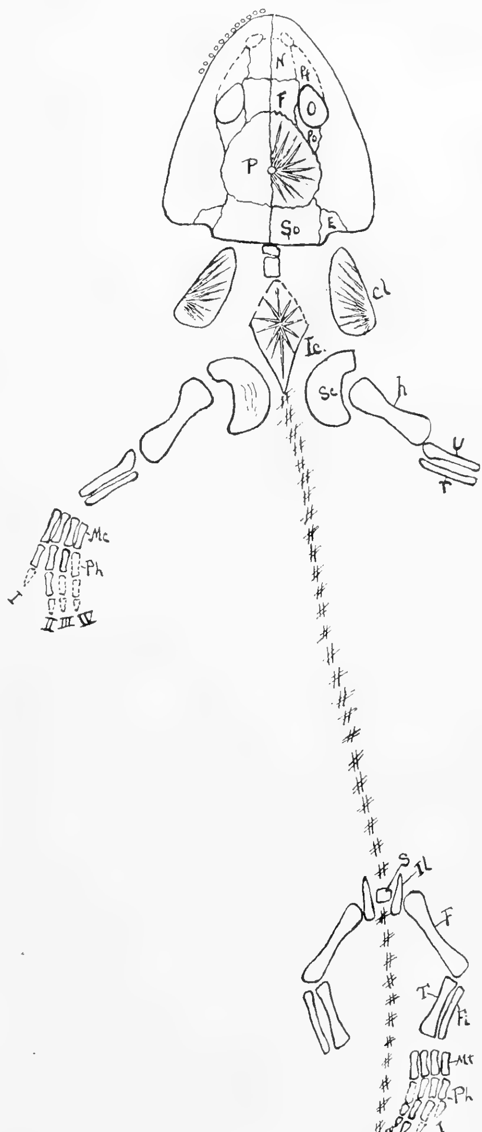

FIG. 10—The skeleton of *Tuditanus minimus* as it is preserved on the black slate. The lettering as in figure 5. ×2.

skull. Together the parietals form a wide oval inclosing on the median suture the circular pineal foramen. The parietals are sculptured with coarse radiating grooves and ridges much after the manner of *T. radiatus*. The pittings present on that form are, however, absent here. The sutures bounding the supraoccipital are tolerably well assured and these show that element to have been rather large, quadrate and with the usual relations for the element. The epiotic is distinct. It is triangular and small. It is produced into an angle on the posterior border strongly recalling a similar condition in *T. punctulatus* Cope. The boundaries of the prefrontals and the upper borders of the maxillae are not clearly ascertained. They may have had the outline indicated (Fig. 11). The lachrymal has not been detected. The postfrontal and postorbital form the posterior boundary of the orbit although the limits of the latter element have not been definitely ascertained. The position of the squamosal is well assured, although its entire boundaries are not determined. It has the usual relations of the squamosal and joins the parietal broadly. The jugal is broad and widens posteriorly to abut on the supratemporal which, as usual, forms the quadrate angle of the skull. The sutures bounding the quadratojugal and the posterior end of the maxilla are not determined.

There are but two fragmentary vertebrae preserved and an estimate based on the length of these remains gives about thirty presacral vertebrae. The structure of the vertebrae preserved cannot be ascertained but the neural spines appear to have been low and stout.

There are six elements of the pectoral girdle preserved. These are: the two clavicles, the interclavicle, the coracoid of one side and the scapulae. The interclavicle is rhomboid in form and acuminate posteriorly. It is sculptured with radiating grooves and ridges. The interclavicle is different from the same element in *T. punctulatus* Cope in that the base is acuminate, not truncate, as in the latter form. The clavicles present much the same shape as does that element in *T. tabulatus* Cope. It is ornamented by a sculpturing of radiating lines which take their origin from the lower external angle as the bone lies in the matrix. The clavicle is somewhat triangular in shape and lies close to the skull, but this close approximation of the pectoral elements to the cranium is due probably to post-mortem shifting since

the scapulae are shifted as far backward. There can be little doubt however that the pectoral arch was not far removed from the cranium. There is an oval fragment preserved on the left of the specimen which I take to be a portion of the coracoid. The scapula is preserved entire on the left side and it is represented by fragments on the right side. It is almost semicircular in form and narrows externally until it is somewhat fan-shaped. There appears to be an ornamentation of lines on the surface of the bone. These lines follow the contour of the anterior border.

The forearm is represented nearly complete on the left side and the right side shows the humerus and the forearm. The humeri are unusual in that they have well-developed articular ends as though the development of the endochondral tissue was well developed in the form. The humerus is expanded at the ends and it is larger at the upper than at the lower end. The ulna is expanded at the proximal but is more attenuated at the distal portion. It is shorter than the humerus by about one-third of its own length. The radius is a mere slender rod of bone and presents the well-developed articular ends. It is slightly shorter than the ulna. The carpus is unossified and its position is represented by a blank space. There are phalanges of four digits preserved and this, apparently, represents the entire number of digits. There is one digit, the second, which has all of the phalanges preserved and they are four in number. The phalangeal elements like the other bones of the extremity have the articular surfaces prominent. The terminal phalanx is claw-like.

There are no ribs nor traces of them preserved and a conjecture as to their character cannot be hazarded since they are known in but two other species, in which they are curved. There is no evidence of a ventral scutellation and so far as is at present known this structure is absent from all of the species of the genus or at least it is but weakly developed. It is not present in the well-preserved *T. sculptilis* described below.

Of the pelvis the ilium alone is represented. The bone itself has disappeared and has left a depression which shows this element to have been an elongate rod very similar to that described for *Micrerpeton.* The sacral vertebra seems to be indicated by a depression between the iliac depressions.

One hind limb is preserved nearly entire and the greater part of the other is also preserved although the phalangeal elements are somewhat disturbed. The femur is slender and more elongate than the humerus. It has well-formed, rounded, articular ends. The tibia presents unusual characters in that its ends are truncate as though the cartilage composing its articular surfaces was not so highly calcified as in the other limb bones. It is somewhat expanded at the ends and is throughout its length broader than the femur. The fibula like the tibia is a slender rod of bone although it is somewhat shorter than is that element. The tarsus is unossified and its position is occupied by a blank space. Portions of both feet are preserved, but only one digit in the right foot is complete. The elements of the other digits are restored. The metatarsals are elongate and slightly expanded at the ends. There are four phalanges present in the complete digit which may represent the third but more possibly the fourth, and the first digit is wanting. The only terminal phalanx preserved is claw-like.

MEASUREMENTS OF *Tuditanus minimus* MOODIE

	mm
Median length of skull	15
Width of skull at posterior border	16
Length of orbit	3.5
Width of orbit	2
Interorbital width	2.5
Length of clavicle	6
Width of clavicle, maximum	3.5
Length of interclavicle, estimated	5
Width of interclavicle	3.5
Length of scapula	3.5
Width of scapula, maximum	2.5
Length of coracoid (?)	2
Length of humerus	4
Length of radius and ulna	3
Length of metacarpal	1
Length of ilium	2.5
Length of femur	4.5
Length of tibia and fibula	3
Length of foot	3.5
Length of metatarsal	.75

The specimen is from the Cannelton slates, Middle Kitanning, near Cannelton, Pennsylvania. It is No. 4,555 of the U. S. National Museum Collection.

TUDITANUS SCULPTILIS sp. nov.

(Figs. 11, 12)

There is preserved in the collections of Walker Museum a small amphibian skull pressed flat on a slab of slate from Cannelton, Penn-

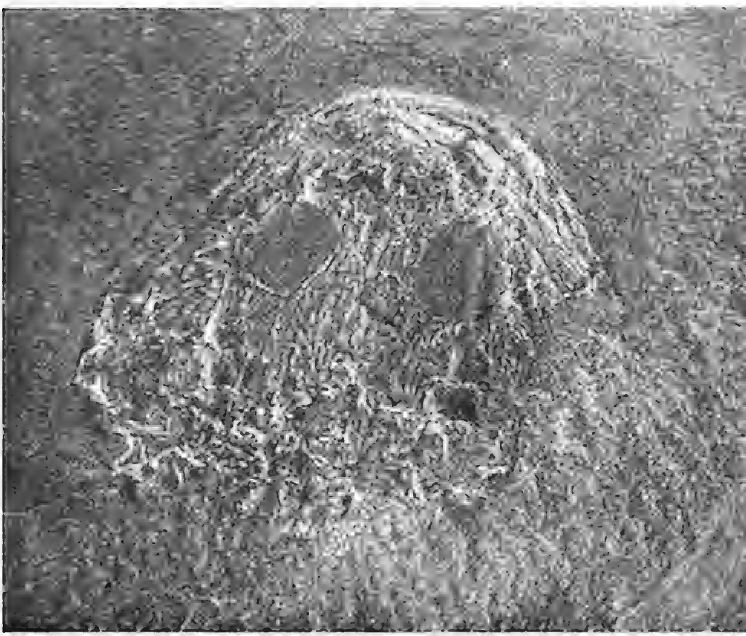

FIG. 11.—The skull of *Tuditanus sculptilis* as it is preserved on the slate. ×3.

sylvania. This specimen formed a part of the Hall Collection recently acquired by the University of Chicago. It is No. 12,315, U. of C.

The specimen presents only a portion of the skull and fragmentary pectoral plates. The skull is wider than long and the muzzle is broadly rounded. The orbits are narrow ovals and their posterior border falls on the transverse line dividing the skull equally. The interorbital width is slightly greater than the width of the orbits and about equal to their length. The posterior outline of the skull is

somewhat truncate as in *T. tabulatus* Cope and other species of the genus. The distal extremities of the quadrates do not project as far backward as do the supraoccipitals. The skull roof is formed of the regular elements except that a quadrate seems to be indicated by a scale of bone on the posterior angle. The nostrils are oval and the pineal foramen is small.

The premaxilla is probably a relatively large element though its boundaries are not definite. The nasal is of an oblong shape and

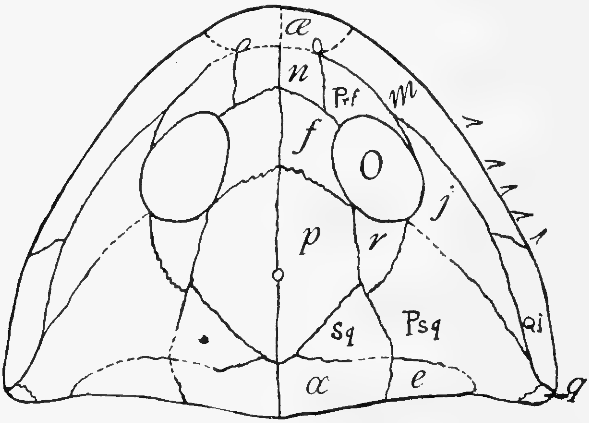

FIG. 12.—The elements of the cranium of *Tuditanus sculptilis*. Ae = premaxilla; e = epiotic; f = frontal; j = jugal; m = maxilla; n = nasal; O = orbit; p = parietal; q = quadrate; qj = quadratojugal; Psq = supratemporal; r = postfrontal; sq = squamosal; prf. = prefrontal.

borders the frontal anteriorly. The frontal forms the whole of the interior border of the orbit and borders the parietal broadly behind. The parietal is a large element and the pineal foramen is inclosed in the median suture about midway of the parietals. The supraoccipital is wider than long and with the epiotic forms the greater part of the posterior border of the skull. The prefrontal apparently forms the entire anterior border of the orbit and sends an acuminate projection to the side of it. The maxilla is excluded from the orbit and is an elongate element with sharp conical teeth of which there are four preserved. These measure about one millimeter in length. The jugal lies along the lateral border of the orbit and it is acuminate both anteriorly and posteriorly. It borders the supratemporal

broadly. The postorbital has not been detected. The postfrontal forms the greater part of the posterior boundary of the orbit. It is triangular and acuminate behind. It is bordered broadly by the parietal and supratemporal. The squamosal element is also triangular and it borders the parietal broadly. The supratemporal is evidently the largest element in the skull and on its posterior corner there is a flake of bone which may represent the quadrate though this is by no means certain. The quadrate has not been detected in any of the Carboniferous Microsauria so far studied although it is well developed in the Permian microsaurian, *Diplocaulus*. The epiotic is an elongate element in the transverse line of the skull. Its entire boundary is uncertain though a part of the sutures are present. The quadratojugal is elongate and lies posterior to the maxilla and with that element forms the lateral border of the skull.

The canals of the lateral line system have not been detected on the skull. The sculpturing of the cranial elements consists of grooves and ridges which radiate from a center. They are more prominent on the parietals than elsewhere although the other skull elements present a strong sculpturing.

There are also preserved on the slab of slate about ten millimeters posterior to the skull fragments of pectoral plates, probably representing the clavicles and interclavicle. They are so badly fractured that the form cannot be determined. No limbs or vertebrae have been observed.

Measurements of the Skull of *Tuditanus sculptilis* Moodie

	mm
Length of the skull in median line	20
Width of skull at posterior border, estimated	24
Diameter of orbit	3
Length of orbit	4
Interorbital space	4
Diameter of nostril, less than	1

Pineal foramen about one-half mm in diameter.

Diceratosaurus laevis sp. nov.

(Figs. 13, 14)

The genus Diceratosaurus was established by Jaekel[1] for the reception of the species described by Cope as *Ceraterpeton punctoline-*

[1] *Neues Jahr. Mineral.* 1903, p. 112.

atum from the deposits of Linton, Ohio. There are good evidences that the species does not belong in the genus *Ceraterpeton* and Jaekel's genus will undoubtedly stand. There are now known three species of this group, two of which are described herewith.

FIG. 13—The skull of *Diceratosaurus laevis* ×2.

The species *Diceratosaurus laevis* is represented by an almost perfect skull (Fig. 13) in the American Museum collection. It is from the mines at Linton, Ohio and had been identified by Cope as *Tuditanus radiatus*. The specimen consists of the bones of the cranial roof, the bones themselves having disappeared. It is not probable that the skull bones were smooth. The details in the structure of the skull have all been ascertained quite definitely, and there can be no doubt that the arrangement of the cranial elements as shown

in Fig. 14 is accurate. As in *Tuditanus tabulatus* Cope the squamosal is excluded from the parietal.

The form of the skull at once recalls that of the species *D. punctolineatus* Cope as figured by Jaekel. The orbits are located in nearly the same region of the skull and the sutures separating the cranial elements are quite similar in the anterior region of the skull. The species *D. laevis* is based on the divergent character of the horn-like protuberances which project from the supratemporals. The horns of *D. punctolineatus* Cope are convergent. The present skull is also smaller and the parietals in *D. laevis* are much larger than in the type species. In the type species also the pineal foramen is located well forward in the parietal while in the present form the foramen is located well posterior.

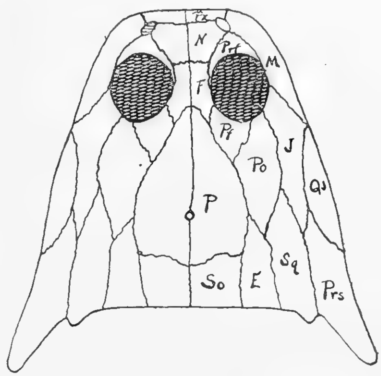

FIG. 14.—The elements of the cranium of *Diceratosaurus laevis.* E = epiotic; F = frontal; J = jugal; M = maxilla; N = nasal; P = parietal; Pf = postfrontal; Prf – prefrontal; Po = postorbital; Prs = supratemporal; Px = premaxilla; Qj = quadratojugal; So = supraoccipital; Sq = squamosal. ×1.

The skull is almost rectangular. The nostrils are elongate ovals. The orbits are circular and the distance between them is equal to two-thirds of the dimension of the orbit. They are located well forward in the skull and are bounded laterally by the maxillaries. The parietal foramen is situated in the posterior third of the parietals. The nostrils have much the same character as in the type form. They are broadly oval.

The premaxillae are elongate transversely being about twice as long as wide. They are identical in shape and relations with the same elements in *D. punctolineatus* Cope. The nasal is nearly square and forms the interior boundary of the nostril. The frontal is elongate in the median length of the skull and it is acuminate posteriorly where the acumination is inclosed by the parietal and postfrontal. The parietals are by far the largest elements in the cranium. They form together an oval which is elongate in the longitudinal diameter of the

skull. They inclose between them in the median suture the small pineal foramen. They are acuminate in front with a broad truncate posterior base where they are bounded by the supraoccipitals. The supraoccipital is nearly square, being somewhat wider than long. It joins the epiotic and the parietal. The epiotic is elongate in the longitudinal diameter of the skull. It ends anteriorly in a point which is inserted between the postorbital and the parietal. The epiotic bears a short protuberance posteriorly much as does the same element in the type species. There are four elements which take part in the formation of the posterior border of the skull. These are: the supraoccipital, the epiotic, the squamosal and the supratemporal. It is very unusual for the squamosal to reach the posterior edge of the cranium. The prefrontal lies anterior to the orbit of which it forms the anterior border. It has the usual relations. The lachrymal has not been detected although Jaekel[1] has identified it in his drawing of the skull of the type species. The maxilla is elongate and forms the lateral border of the skull. No teeth have been detected although they were doubtless the same as Jaekel has figured in *D. punctolineatus* Cope. The jugal is an elongate element joining the maxilla posteriorly. Jaekel included this element in his "perisquamosal" but the sutures are clearly evident in this specimen and no "perisquamosal" has been identified. The postorbital is fully as large as the jugal which it joins. It forms a part of the posterior border of the orbit and it ends posteriorly in a point which is inclosed by the epiotic and the squamosal. The postfrontal with the foregoing element forms the entire posterior border of the orbit and it likewise ends in a point inclosed by the parietal and the postorbital. The quadratojugal has much the same shape and relations as in *D. punctolineatus* Cope, although it is located farther back. The squamosal is also elongate as are most of the posterior cranial elements and it likewise has an acumination which is directed forward and is inclosed by the postorbital and the jugal. The squamosal abuts onto the posterior border of the skull. The anterior suture of the supratemporal element is rather indistinct but it is, I believe, as represented. The element is elongate and is prolonged posteriorly to form the horn, which ends in a blunt point and is not sharp as in the type species.

[1] *Op. cit.*

On the basis of the "perisquamosal," which Jaekel claims for *Diceratosaurus punctolineatus* Cope, the genus was regarded by that author as without a parallel among the known vertebrates. Such it would be if Jaekel's interpretations are correct but the morphology of the present skull would tend to throw grave doubt on the interpretation of this region of the skull as given for the type species. Another specimen representing another species also shows no evidences of the fusion of elements to form the "perisquamosal" and its presence in the type species is doubtful. So far as I can learn there has never been a true case of fusion in any of the cranial elements of the Stegocephala unless it be between the frontals of *Diplocaulus magnicornis* Cope, and I think I can detect a median suture even here. It was on the basis of such fusions that Maggi has proposed to derive the interparietal of the primates from the epiotics of the stegocephalans.

The posterior outline of the skull in the present specimen is not well preserved and the outline as given may be slightly inaccurate. The indentation figured by Jaekel in the posterior border of the skull of the type form is not present in the species under discussion.

MEASUREMENTS OF THE SKULL OF *Diceratosaurus laevis* MOODIE

	mm
Length of skull along median suture	37
Length from muzzle to tip of horn	50
Width between tips of horns, estimated	40
Width of orbit	7
Length of orbit	10
Width of skull across the orbits	30
Interorbital width	6
Length of nostril	2
Width of nostril	1
Diameter of the pineal foramen less than	1

The specimen on which the species is based is from the Linton deposits of Ohio and forms a part of the collection of Dr. J. S. Newberry now in the American Museum. It is No. 102 of the American Museum Collection.

DICERATOSAURUS ROBUSTUS sp. nov.

(Fig. 15)

The present species is indicated by the left portion of a cranium representing a large individual. The characters of the skull are so

clearly marked that it seems worthy of description. The presence of horns as given in the restoration of the skull is based on the analogy with the other two species of this genus in both of which horns are present. The generic determination of the species is based on the large size of the postorbital which is essentially characteristic of the other species of *Diceratosaurus*.

The characters which distinguish the species from the others of the genus are the large postorbitals and the small parietals which are excluded from union with the postfrontals on account of the large size of the frontal. In the other two known species the frontal is small and the parietal comes forward to join the postfrontal. The present species exhibits a skull which is nearly twice as large as that of *D. laevis* and nearly three times the size of the skull of *D. punctolineatus*.

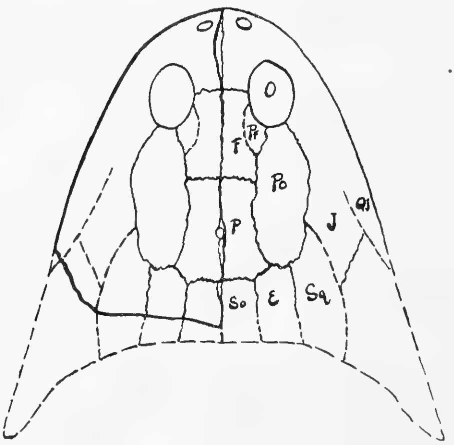

FIG. 15.—The skull of *Diceratosaurus robustus*. E = epiotic; F = frontal; J = jugal; Pf = postfrontal; P = parietal; Po = postorbital; Qj = quadratojugal; So = supraoccipital; Sq = squamosal.

The portion of the skull preserved shows the cranium to have had a rather acuminate snout, not blunt as in the type species. The orbit is an elongate oval although it has the same relative position in the skull as in the other species. The nostril is indicated by an oval depression near the anterior edge of the skull. The frontals as indicated by the sutures present on the portion of the skull preserved are fully as long as the parietals. Whether they were as wide as is represented in the drawing (Fig. 15) is uncertain. The postfrontals are represented by very small bones the sutures of which are somewhat uncertain although they cannot be far from what is represented in the drawing. The postorbital is large and elongate. It is distinctive of this species on account of its unusual size and of the genus as well,

although it does not attain such proportions in the other known forms. The parietals are elongate and narrow. The pineal foramen is represented by its lateral edge and its position is about midway of the longitudinal diameter of the parietals. The supraoccipital is represented by its anterior border. It is narrow. As restored it may be too long. The epiotic also is represented by an anterior portion and it shows this element to have the position and form which is typical of the form *D. laevis*. Such other of the cranial elements as are indicated are based on the relations discovered in *D. laevis*.

The heavy line on the left of the drawing represents the outline of the portion preserved. The skull, as restored, may be a little too long, and the shape of the horns is conjectural. In the orbit there are preserved two teeth showing longitudinal fluting. The longest tooth is about three millimeters.

Measurements of the Skull of *Diceratosaurus robustus* Moodie

	mm
Median length of the skull, estimated	67
Posterior width of the skull, estimated	78
Length of orbit	18
Width of orbit	12
Length of postorbital	27
Width of postorbital	14
Length of longest tooth	3
Width of same tooth at base	15

This specimen is from the coal mines of Linton, Ohio. It forms a part of the Newberry collection of the American Museum where it is No. 8,611 G.

Ichthyerpeton squamosum sp. nov.

The present species is based on well-preserved remains from the Linton, Ohio, beds. There are two specimens of the species preserved on blocks of bituminous coal and they represent the greater length of the animal. The species is located in the genus *Ichthyerpeton*, which was based by Huxley[1] on remains from the Coal-measures of Ireland (Fig. 16), on account of the character of the dermal covering which consists of small overlapping scales such as

[1] *Trans. Roy. Irish Acad.*, 1867, p. 351.

Huxley described for the form from Ireland. The specific characters of this form are the small size of the rounded scales, the attenuated tail, the apparent absence of limbs, the character of the ventral scutellation and the slightly curved condition of the ribs.

From the preserved remains it is estimated that the animal attained a length of not less than three feet and its body was long and slender and it may have had an appearance similar to that of a *Siren* or a *Proteus*. The slenderness of the body is a variance from the condition found in the type species, *Ichthyerpeton bradleyae* Huxley (Fig. 16)

FIG. 16.—The impression of *Ichthyerpeton bradleyae* Huxley. After Huxley.

in which the trunk was rather stoutly built. The character of the anterior portion of the body in the present species cannot be determined and the skull is wanting. There are no evidences of anterior limbs although the ventral scutellation preserved would seem to include the pectoral region. No pectoral shields are preserved nor are there any traces of pelvic elements or limbs.

The preserved portions on one block include nearly the entire tail and the posterior of the body and on the other block the dorsal region of the body and the anterior portion of the tail, so that the specimens supplement each other in an interesting manner. There are impressions of several vertebrae preserved. They are much of the same character as Huxley has described for the type species. They are short and thick and were probably amphicoelous. There are preserved the remains of rather slender recurved ribs mingled in with the

remains of the ventral scutellation and distinguished from the elements of the abdominal shield by their size and curvature. They were apparently single-headed, but the character of their articulation cannot be determined. The ventral scutellation consists of fine continuous rods arranged in the regular chevron pattern. They do not seem to be divided into oat-shaped scutes as is the case with the form described by Huxley. The ventral rods are closely packed for a distance of more than six inches but as they are scattered their exact arrangement cannot be determined. They seem to have extended to the cloacal region but there are no evidences of the specialized clasping organs such as are developed in the ventral armature of *Ophiderpeton.* The scales which are well preserved on the tail, may have covered the entire body since there are many scattered scales in the dorsal region of one of the specimens. The scales are slightly oval, tuberculate, and they measure scarcely one millimeter in their longest diameter. They show but slight evidences of having been imbricated though they may have been so although they may have been inclosed in the integument and somewhat separated from each other. The most posterior part of the tail preserved seems to indicate that the tip was attenuated. It was probably flattened from side to side. We may thus regard *Ichthyerpeton squamosum* as an elongate aquatic animal with a long flattened tail, and since there were possibly no limbs it would be an animal highly adapted for life in the water. The present species is of interest because it represents for the first time the discovery of the scaled Amphibia in the deposits of North America.

MEASUREMENT OF THE TYPES OF *Ichthyerpeton squamosum* MOODIE

Length of the animal as estimated from the two impressions	3 feet
Length of longest impression	21 inches
Length of specimen containing tail impression	9 inches
Width of tail impression, maximum	50 mm
Width of tail impression, minimum	6 mm
Width of a single scale	1 mm
Chevron rods in a distance of three mm	8
Distance from base of tail to the tip	125 mm
Width at base of tail	00

SECOND SPECIMEN

Length of specimen as preserved	225 mm
Width of chevron rod space	30 mm
Length of rib	25

The species is based on two specimens which form part of the Lacoe collection belonging to the U. S. National Museum where they are Nos. 4,476, and 4,459. The specimens are preserved on two blocks of bituminous coal from the mines at Linton, Ohio.

MACRERPETON HUXLEYI Cope

(Fig. 17)

The new genus *Macrerpeton* is proposed for the reception of the species of amphibian described by Cope as *Tuditanus huxleyi.*[1] This form he placed provisionally in the genus *Tuditanus* since it seemed to present the same type of sculpturing of the cranial elements similar to that found in *T. radiatus* Cope. Even this species, in all probability does not belong in this genus but it cannot be removed at present. Closer study of the type specimen of *Tuditanus huxleyi* Cope shows great variation from any of the species described from Linton, Ohio, and indeed from any Carboniferous form thus far known.

The specimen represents the left side of the face of a form which seems to approach the higher labyrinthodonts in the shape of the skull. The orbit is far removed from the border of the skull and taking the median line of the skull as somewhat further inward than the part preserved we have a skull which cannot be far from the figure (Fig. 17). The left posterior angle of the skull seems to be represented by a depression on the face of the block of coal on which the specimen reposes. The arrangement of the bones as given in the diagram (Fig. 17) strongly recalls that of *Capitosaurus* from the Keuper of Europe. The anterior border of the skull is restored after the skull of *Capitosaurus* but the skull may have been pointed as in *Archegosaurus*. The character of the teeth would seem to be such as to refer the form to a labyrinthodont. The teeth are very

[1] *Rept. Ohio Geol. Surv.*, 1875, p. 397.

strong and curved backwards and they have the strong longitudinal fluting which is characteristic of many of the labyrinthodonts. Another character which would distinguish the form is the pattern of the cranial sculpture. This consists of inosculating pits and grooves

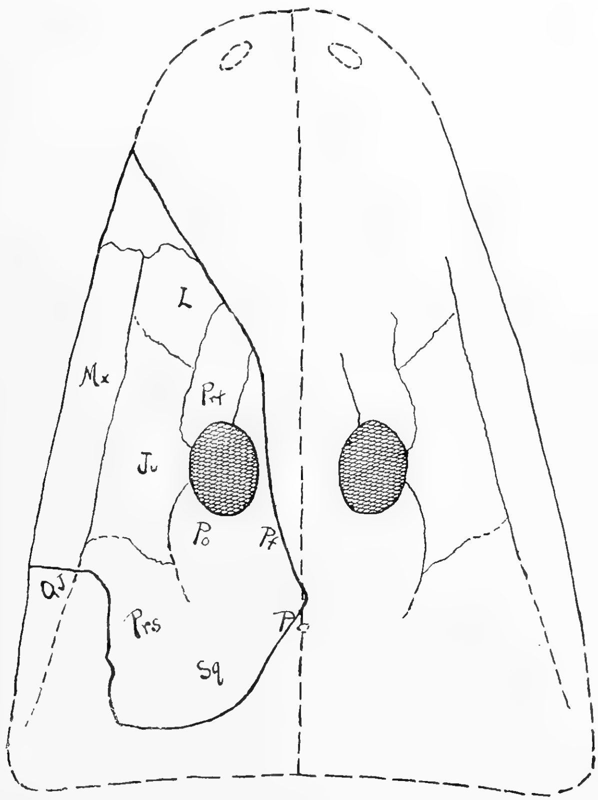

FIG. 17.—Restoration of the skull of *Macrerpeton huxleyi* Cope. One-half natural size.

of a coarse character and compares favorably with the sculpturing of the later forms like *Anaschisma* from the Trias of Wyoming. If this form really represents a labyrinthodont-like form it is the oldest of the kind so far known since in all probability the *Eosaurus* vertebrae come from a higher horizon. The specific characters have been given by Cope and further discussion will be deferred.

SAUROPLEURA LONGIDENTATA sp. nov.
(Figs. 18, 19)

This species may be distinguished from the other members of the genus by the large size and shape of the cranium and by the broad mandible with its very long teeth. The skull of *Sauropleura digitata* Cope is not known but the body of that animal as preserved represents far too small a form for the skull to be referred to that species. The skull of the present species is fully half as long as the dorsal region of *S. digitata* Cope so that an association of the remains would be incongruous. From the skull of *S. scutellata* Newb. the present skull differs in size and proportions. The skull of *S. scutellata* is narrow while the skull of *S. longidentata* is quite broad. The teeth of the latter are characteristic of the species since in all of the other species of the genus where the skull is preserved the large anterior tooth is wanting.

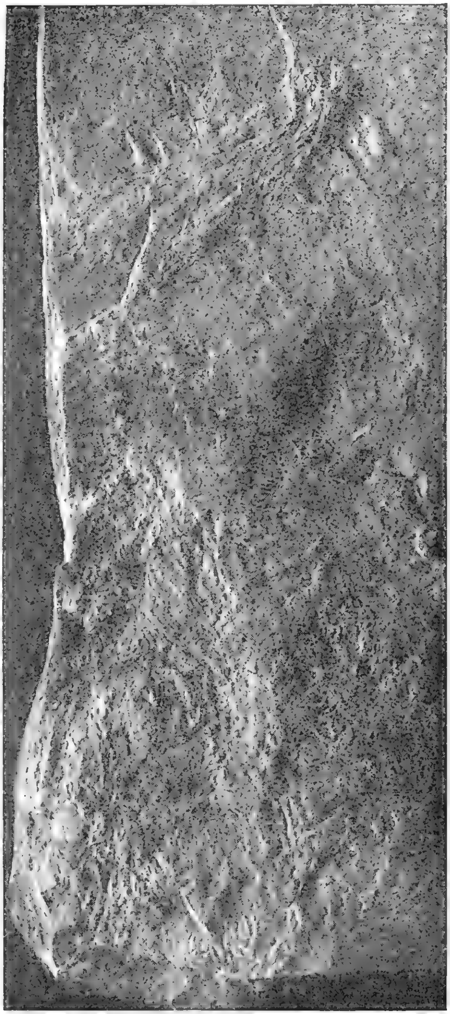

FIG. 18.—The type specimen of *Sauropleura longidentata*. Natural size.

Of the species *Sauropleura longidentata* there is preserved the right half of a cranium (Fig. 18) and the greater portion of the mandible belonging to the same individual. The bones

show the coarse sculpturing of the larger species of the Microsauria and it consists more of radiating grooves than of pits. The skull, as restored, is broadly ovate, with the posterior border truncate. The muzzle is broad and the nostrils are, apparently, located near the anterior margin. The pineal foramen cannot be detected. The posterior border of the orbits lies near the median transverse line of the skull. They are circular and are removed some distance from the margin of the cranium. Only the frontal and parietal can be

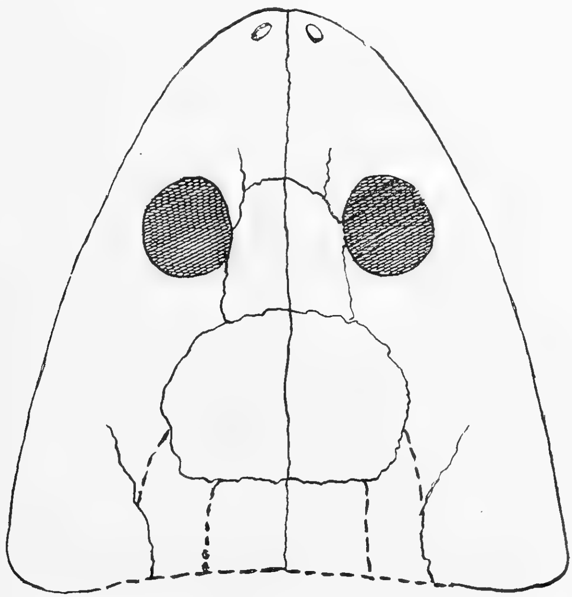

FIG. 19.—The cranium of *Sauropleura longidentata*. Natural size.

determined with certainty. These are seen to be rather large and have the usual relations of those elements.

The lower jaw is heavy and it is provided with heterodont teeth, which were possibly pleurodont, though this cannot be determined since the specimen lies on its inner side. Near the anterior end of the mandible there is a very long fang-like tooth, longitudinally striated, which rises from a broad base and rises to considerable prominence. It is slightly recurved. The other teeth are smaller though the next

succeeding one is still of considerable size. All of the teeth preserved are longitudinally striated but only the two anterior ones are recurved to any extent.

Measurements of the Type of *Sauropleura longidentata* Moodie

	mm
Length of the skull in median line	75
Width of skull at posterior border, estimated	80
Width of skull across orbits, estimated	60
Width of orbit	10.6
Length of orbit	12
Interorbital space	16
Length of jaw, as preserved	48
Width of jaw, maximum	16
Width of jaw, minimum	5
Length of longest tooth	11
Width of longest tooth at base	4.5
Length of shortest tooth	3
Width of shortest tooth at base	1

This specimen forms a part of the Newberry collection of the American Museum of Natural History where it is No. 8,619 G.

Eoserpeton tenuicorne Cope gen. nov.

(Fig. 20)

The new genus *Eoserpeton* is erected for the reception of a single species originally described by Cope as *Ceraterpeton tenuicorne.* It cannot be placed under the genus *Ceraterpeton,* however, on account of the form and structure of the skull which varies widely from that of the type species of *Ceraterpeton, C. galvani* Huxley. The most important character in which the present species differs from *C. galvani* Huxley is the peculiar form taken by the prosquamosal as well as the fact that it is the epiotic which has the horn-like projection in *C. galvani* Huxley while in *Eoserpeton tenuicorne* Cope it is the supratemporal which bears the projection. The present species also lacks the projection at the side of the skull which is characteristic of the *Ceraterpeton.* No undoubted remains of the genus *Ceraterpeton* occur outside of England and Ireland, so far as I am aware. Fritsch referred a species, provisionally described as *Scincosaurus crassus,* to this genus but Andrews, Jaekel, and Woodward all agree that the species does not belong under *Ceraterpeton.* Jaekel even says there

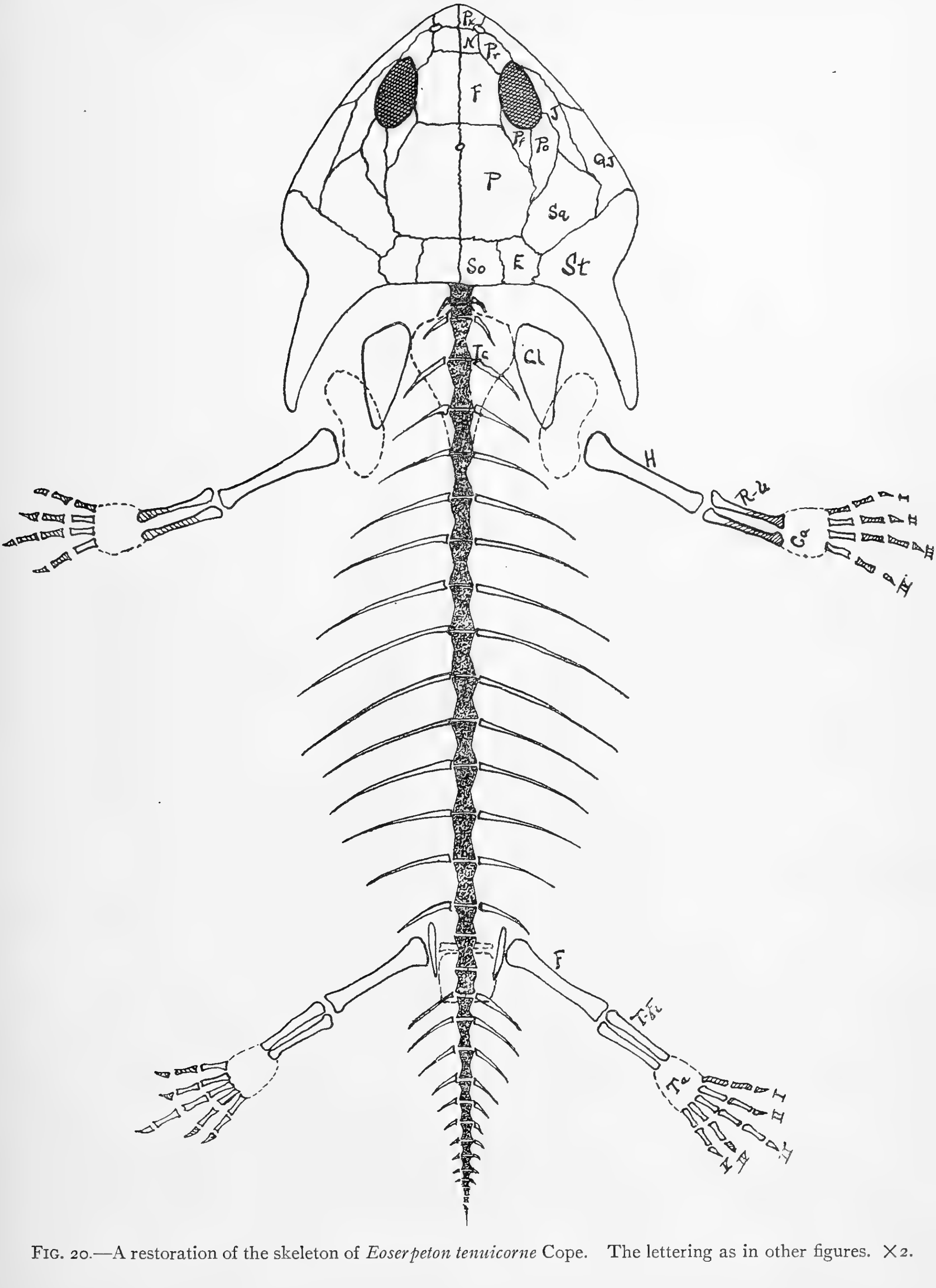

FIG. 20.—A restoration of the skeleton of *Eoserpeton tenuicorne* Cope. The lettering as in other figures. ×2.

are no horns in the species *Scincosaurus crassus* Fritsch. Cope described three species from the coal deposits of Ohio under *Ceraterpeton* but none of them belong there. Jaekel has defined one species so described, *C. punctolineatum* Cope, as *Diceratosaurus punctolineatus*

FIG. 21.—The impression of the skull of *Stegops divaricata Cope*. ×2.

Cope and the other species is described here under the new genus *Eoserpeton*. The new genus is characterized from *Diceratosaurus* of Jaekel by the divergent character and shape of the horns, the shape and organization of the skull and by the form and position of the orbits.

The restoration of the species *Eoserpeton tenuicorne* Cope is based

on three specimens two of which represent the larger part of the animal and the other is a large skull in which the characters of the cranium have been detected. The two specimens in the National Museum at Washington (Nos. 4,472 and 4,473) are impressions of the same individual. It differs from the specimen in the horns being slightly incurved as represented in the drawing. This latter form was described by Cope in 1897.

STEGOPS DIVARICATA Cope gen. nov.

(Figs. 21, 22)

The genus *Stegops* has been erected for the reception of the peculiar form described below. This species was first described by Cope as *Ceraterpeton divaricatum*[1] but there are very good reasons why the form cannot be retained in this genus nor can it be placed in either the genus *Eoserpeton* or *Diceratosaurus*. The entire shape of the skull, the character of the horns and the presence of a large lachrymal are distinctive characters of the new genus *Stegops*.

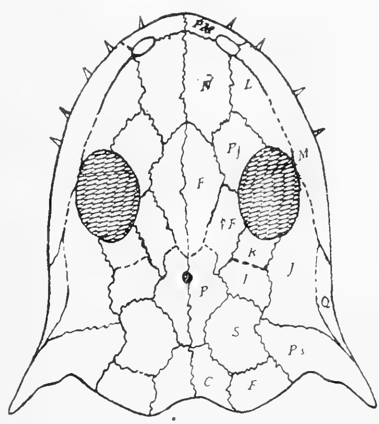

FIG. 22.—The outline of the cranial elements of *Stegops divaricata* Cope. The lettering as in other figures except I = intertemporal (?). ×1.

The remains on which the new genus reposes consist of the impressions of a single well-preserved skull from the coal mines at Linton, Ohio. The chief characters which distinguish the genus will also serve to differentiate a new family of Microsauria which may be known as the STEGOPIDAE. The chief family characters are the large lachrymal unknown in any of the other species of Carboniferous Amphibia, the central position of the orbits, the general form of the skull, and the peculiar short divaricate horns. If an intertemporal element is present in the skull, which is suggested as a possibility, the family is further distinct.

[1] *Proc. Amer. Phil. Soc.*, 1885, p. 406.

SAURERPETON LATITHORAX Cope gen. nov.

(Fig. 23)

The new genus *Saurerpeton* is erected for the reception of the species described by Cope in 1897[1] as *Sauropleura latithorax.* The characters which distinguish the genus not only from *Sauropleura* but from all other known Microsauria are the broad plate-like character of the ventral scutellation, the broad rounded character of the pectoral plates, and the broad short skull. The structure (Fig. 23) of the skull

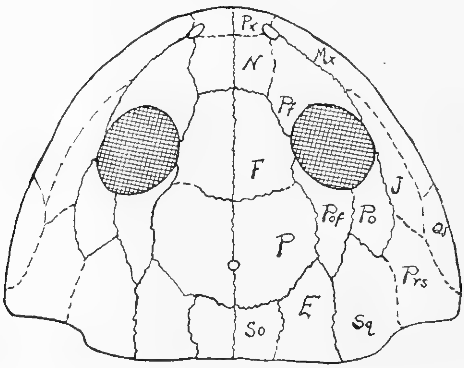

FIG. 23.—Outline of the cranial elements of *Saurerpeton latithorax* Cope. Less than natural size.

is nearest to that of the genus *Diceratosaurus* but the present form lacks the horns and the shape of the skull is also far different from that of the species of *Diceratosaurus.*

The skull of *Saurerpeton latithorax* Cope is broad and heavy. The teeth are heterodont. The body is broad and stout and the limbs are of unusually strong proportions. The ventral armature consists of broad imbricating scutes which form a single piece across the abdomen and are but slightly angulated to form the chevron. All other known Microsauria have the chevron armature strongly angulated and the scutes are usually long and slender. A distant approach to the condition of *Saurerpeton* is found in the *Ctenerpeton,* but the peculiar comb-like expansions and the shape of the body in the latter distinguish the two forms.

[1] *Proc. Amer. Phil. Soc.*, 1897, p. 86.

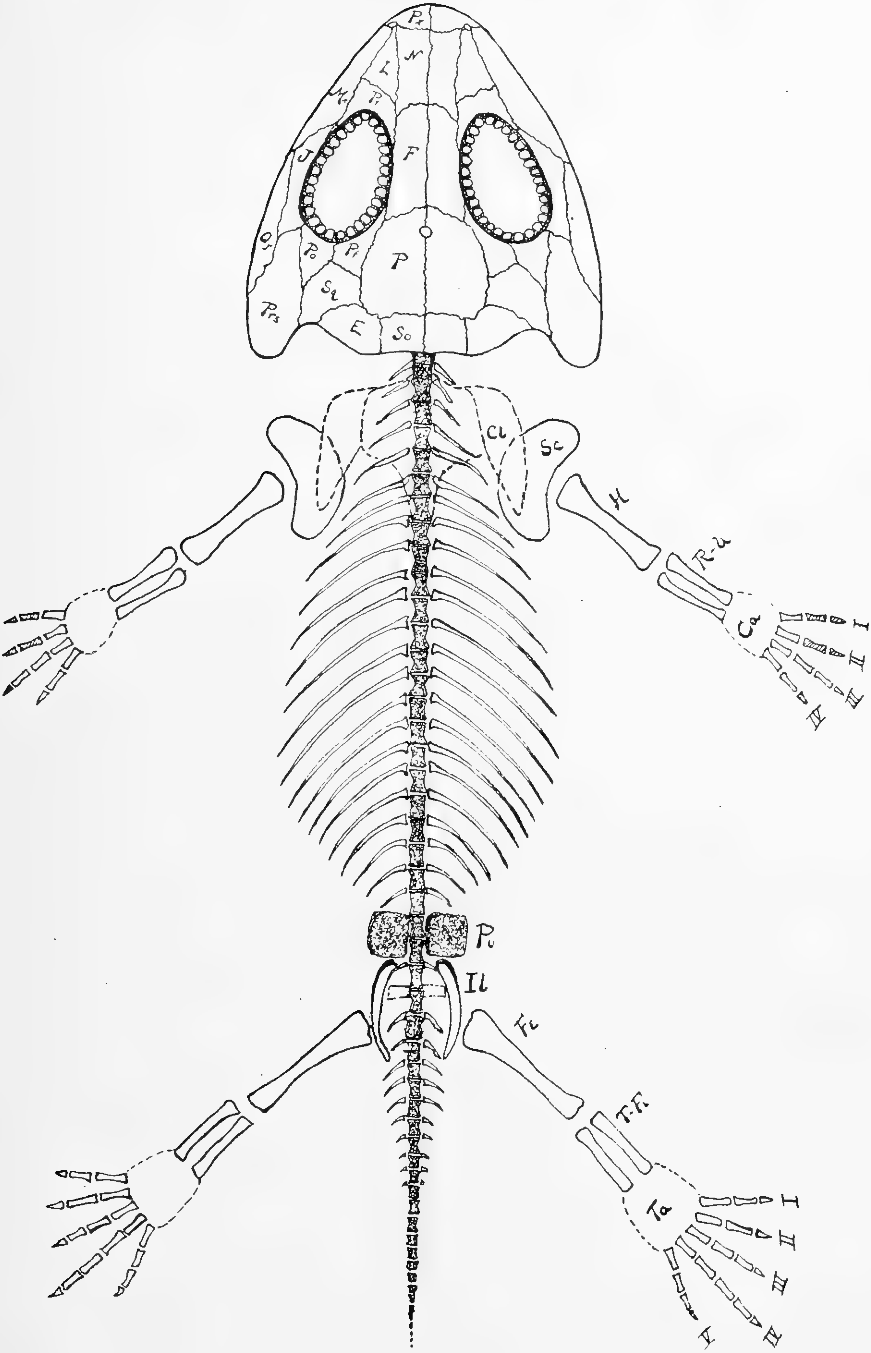

FIG. 24.—A restoration of *Amphibamus grandiceps* Cope.

AMPHIBAMUS GRANDICEPS Cope

(Fig. 24)

This well-known species from the Mazon Creek deposits is restored herewith. The restoration is based on a specimen, nearly complete, in the collection of Mr. L. E. Daniels of LaPorte, Ind., and on the drawings of Cope.

In conclusion I wish to express my hearty appreciation to Drs. S. W. Williston and Stuart Weller for the interest they have taken in my work and for the help I have received from them.

THE ANCIENT KOBUK GLACIER OF ALASKA

OSCAR H. HERSHEY
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Between Hotham Inlet and Kotzebue Sound, on the Arctic coast of Alaska, there is a long narrow strip of rolling upland which is probably (in part at least) a glacial moraine. The portion I saw in the summer of 1906 (from Cape Blossom north) consists of broad, smooth ridges, probably rising 50 to 150 feet above sea-level, bordered on the west and north by a sea-cliff from 30 to 100 feet high. The tundra vegetation on the upland surface completely obscures the nature of the underlying material, but its character may be inferred from many fairly good exposures in the sea-cliff.

The northwestern corner of this upland is protected from present marine erosion by a triangular strip of lowland bordered by a beach ridge from 5 to 12 feet high, behind which there are lagoons and marshes. The Friends' Mission at Kikiktak or Kotzebue Post-office is situated on the beach ridge near where it makes a sharp bend from north to east and about one and one-half miles from the old sea-cliff. The latter, where thus protected, is broken down and tundra-covered so that there are no satisfactory exposures of the underlying material.

About two miles east of the mission, the cliff presents, along a distance of half a mile, a number of imperfect exposures of typical till. It is a stiff blue-gray clay abounding in rock fragments in sizes up to eighteen-inch boulders. They consist of many rock species, but varieties of gabbro, probably derived from Mendenhall's Kanuti series,[1] are the most conspicuous. Most of the pebbles, cobbles and boulders are somewhat rounded, in the manner characteristic of glacial abrasion, noticeably differing from similar material after having been exposed for some time to wave action on the beach. Very many

[1] Walter C. Mendenhall, "Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by Way of Dall, Kanuti, Allen and Kowak Rivers," U. S. Geological Survey, *Professional Paper No. 10*.

of the faceted pebbles and boulders are striated; indeed, a few minutes' search yielded some of the finest scratched stones I have ever found.

Owing to the masses of tundra soil that have fallen down the cliff, the upper limit of this apparent glacial deposit is obscured but appears to be quite irregular. It is overlaid by a thick bed of dark blue-gray laminated silt and muck, which is better exposed than the boulder clay. In places the silt forms steep banks 30 feet high, reaching down to sea-level. In other places the boulder clay reaches from 3 to 6 feet above the water and at one place fifteen feet, being there overlaid by only about ten feet of silt. The fine lamination, absence of gravel or coarse sand, and the presence of much peat in the silt at first suggested to me that it was deposited in a lagoon (at a time the land was lower) behind a beach ridge which has been completely destroyed by marine erosion.

The boulder clay has a character typical of ground moraine and it is undoubtedly due to ice action. However, the question may be raised as to the method of its formation and how it reached its present position. This is especially pertinent in view of the fact that this locality is far beyond the reputed limits of Quaternary glaciation in northern Alaska. Three hypotheses are worthy of consideration. The first attributes the boulder clay to the action of shore ice. This would not account for the presence of the clay and the extensive faceting and scratching on all sides of the included rock fragments, for it is inconceivable that the shore ice could work long enough on the same material to produce these features as strongly developed as they are found.

The second hypothesis recognizes the material as till but attributes its present position to transportation by floating ice. The objection to this is that there is too much of it to have been carried *en masse* and that if carried in small quantities and dropped from time to time, it should be mixed with typical marine deposits which so far have not appeared in the exposures.

The last hypothesis, and one which I am inclined most strongly to favor, is that it is a portion of the ground moraine of a great glacier that came out of the mountainous interior of Alaska, probably covering, in part at least, the basin of Hotham Inlet.

About three miles south of the mission, the modern beach ridge approaches the sea-cliff. There are no true exposures of the material in the face of the cliff, but water-worn gravel like the present beach gravel, though probably of a different origin, occurs at several points up to 50 feet above sea-level. This is the seaward edge of a small plain about 75 feet above the sea. Less than a mile south there is a smooth ridge running inland; on its south side there is another broad flat plain extending inland half a dozen miles and probably two miles wide along the sea-cliff. Its altitude is about 75 feet above the sea; on the south it is bordered by another narrow smooth ridge running inland. A few very imperfect exposures on the sea-cliff forming the seaward edge of the plain show pebbleless brown carbonaceous silt, suggesting a lagoon deposit. It is evident to me that the depressions of a rolling upland have been filled with fine silt to a level which, possibly through uplift, is now mostly about 75 feet above the sea. Marine erosion has cut away a large part of these plains and the intervening ridges, producing a sea-cliff from 50 to 100 feet high, at the foot of which lies the modern beach ridge, generally 75 yards wide. There remains to discover the composition of the upland ridges.

At about seven miles south of the mission there is a small lagoon winding about in the marshy floor of the valley whose mouth was originally below sea-level, the 75-foot silt plain above described not being developed here. Indeed, looking over the country south to beyond Cape Blossom, it appears that the smooth ridges generally rise to about 100 feet above sea-level and are separated by valleys of varying widths, generally coming down nearly to sea-level at the beach line. Inland as far as one can see there are no isolated hill peaks; nor, on the other hand, is there a suggestion that the valleys have been eroded from a plain. The topography suggests a constructional surface of a glacial type, not that of a terminal or lateral moraine, but of an undulating ground moraine.

At about half a mile south of the lagoon, the sea-cliff, 60 to 100 feet high, bisects a broad, undulating ridge which leads inland as do the others above described. Stiff blue-gray boulder clay abounding in beautifully glaciated pebbles and boulders (the latter generally gabbro or metagabbro), appears for nearly a quarter of a mile, rising from 10 to 50 feet above sea-level and overlaid by dark blue-gray and

brown carbonaceous silt, 30 to 60 feet thick. I have no doubt that the core of this ridge and presumably of many others in this region is ground moraine. I am surprised and puzzled by the invariable presence over the till, even in the axes of the ridges, of stratified carbonaceous silt. I cannot distinguish between this silt formation and that which in places forms plains between the ridges. It is probable that only one silt formation is present, and that it has an attitude similar to the loess formation in the Mississippi basin, mantling an undulating drift plain. Therefore, the theory that it is a lagoon formation must be abandoned.

(At the upper edge of the bank, on the north side of the ridge south of the lagoon, I found the pelvis of a large animal. It was 8 feet wide. It had evidently been embedded in the soil at the surface of the silt formation.)

A headland about three and one-half miles northeast of the mission presents a 100-foot sea-cliff at the base of which, in places reaching up to 20 feet, occurs the blue-gray till abounding in glaciated boulders, some four feet in length. They consist chiefly of gabbro, metagabbro, pyroxenite, greenstone, diorite, gneiss, schist, marble, limestone, and fine-grained sandstone. The overlying non-pebbly carbonaceous silts form the greater portion of the cliff, but are not well exposed.

Three-fourths of a mile farther northeast, the cliff in a headland is only from 30 to 50 feet high, yet the boulder clay reaches up to 20 feet above sea-level. Boulders from one to three feet in diameter are relatively more abundant than at the outcrops before described. The largest is a dark green altered fine-grained basic volcanic rock.

At "the cape," the bold headland five miles northeast of the mission, that forms the most northerly point of the peninsula, although the sea-cliff is probably 150 feet high, the silt is so thick that the boulder clay does not appear to extend more than about 15 feet above sea-level. From the top of the cliff looking inland two peculiar depressions can be seen. They are occupied by lakes which may be between five and ten acres in extent. The northern side of each is a low valley plain, but the southern side is a crescent-shaped steep bluff. The abruptness of this bluff contrasts strongly with the flowing contours of the neighboring country. It is possible that these

depressions were produced by the melting of large residual masses of glacial ice buried under the silt. I saw a similar bluff in looking over the country back of Cape Blossom.

There is nothing in the topography of the peninsula to suggest the direction of ice movement except that the ridges are prevailingly elongated easterly and westerly. These ridges, in so far as they are above sea-level, consist chiefly of silt, but, as we have seen, cores of boulder clay usually appear where they are bisected by the sea-cliff in a manner to indicate that the present topography is in large part controlled by the surface of the glacial deposit. The topography is not that typical of a terminal or lateral moraine but of a fluted ground moraine. All the till exposures examined corroborate the idea that it is ground moraine. Therefore, I incline to the opinion that these ridges are approximately parallel to the direction of ice movement like the major axis of a drumlin. Indeed, many of the shorter ridges approximate to the drumlin form, and if the silt covering were removed this form might be even more pronounced. Probably the ice that glaciated this country was a great glacier that came out of the broad valley of the Kobuk River on the east and extended into the Arctic Ocean. Mendenhall says:

> All of the peninsula which separates Hotham Inlet and Selawik Lake from Kotzebue Sound and its waters, with the exception of the extreme southwestern point (where members of the schistose series outcrop in Choris Peninsula), is made up of Pleistocene silts, clays, and embedded ice. Its outline and topography suggest that shoals which have formed off the mouths of the Noatak, the Kowak, the Selawik, and the Buckland have been raised into islands by slight local elevations, and that these islands have afterwards been tied into one long peninsula by the action of winds, waves, and currents.[1]

On the contrary, my investigation of that broad portion of the peninsula lying north of the latitude of Cape Blossom has led to the conclusion that it is a remnant of an undulating silt-covered drift plain into which the sea has cut on the western, northern, and eastern sides, producing a cliff from 30 to 100 feet high. The generally undissected character of the upland and the fresh appearance of the till suggest a late stage of glaciation presumably Wisconsin. This opinion is expressed with the fact in mind that erosion and weathering standards of the Temperate Zone are not applicable here

[1] U. S. Geological Survey *Professional Paper No. 10*, p. 45.

where the subsoil is permanently frozen to great depths. Partly coincident with the later stages of cliff cutting, and partly subsequent to the completion of certain portions of the cliff, has been the formation of a modern beach ridge. All parts of the latter are undoubtedly quite recent in age. The spit on which is situated the Friends' Mission consists of several strands, or separate beach ridges, between which are marshy depressions and freshwater lakes at levels from 5 to 10 feet above the level of the sea on one side and a brackish lagoon on the other side.

Presuming that the upland represents as late a stage as the Wisconsin epoch, the earlier stages of the sea-cliff erosion would occupy a larger part of the Recent period, the oldest of the beach ridges would be relatively modern in age and the youngest, on which the mission stands and which is yet in process of formation, would belong to a very late portion of this last epoch, perhaps the last 500 years. The marshy ground immediately behind it would be of similar youth. The age of these beach ridges and marshes is chiefly of interest in connection with the remains of large animals which occur on them.

Extending for about five miles along the northern shore of Hotham Inlet, northeast of the Pipe Spit, there is a sea-cliff from 30 to 75 feet high, interrupted by a valley one-half a mile wide. Sailing within several hundred feet of the western half of the cliff, I noticed in many exposures a stony clay of blue-gray color, doubtlessly till, extending nearly to the top of the bank. On the beach were some boulders derived from the cliff, but this is a less bouldery deposit than the till of the peninsula. Also, the till appears to be in places associated with irregularly stratified beds of sand and gravel. Landing at the eastern end of the cliff, I examined it westward for over two miles. West of the valley above-mentioned, all exposures were of stiff blue-gray till abounding in smoothed and striated pebbles and some boulders which were chiefly of limestone and calcareous schist, a few of greenish altered diorite, quartzite, gneiss, and vein quartz. There is a noticeable absence of the gabbroic rocks so prominent in the drift of the peninsula. The till extends nearly or quite to the summit of the cliff and the silt formation of the peninsula was not identified here.

The portion of the cliff east of the valley, extending about one and

one-fourth miles, is made up of irregularly interbanded till and modified drift. The latter is an indistinctly stratified sand and fine gravel containing many pebbles which yet preserve traces of faceting and striation. The till is a blue-gray sandy clay containing many striated stones and a few boulders, generally of limestone. The smaller rock fragments are mostly schist, limestone, and vein quartz, a drift notably differing in composition from that of the peninsula. Any exposed section of the cliff shows one or several bands of till 5 to 15 feet thick, occurring in places at the base or top, but generally about two-thirds of the distance from the bottom. Where at the top, it forms small stony knolls in the rolling upland back of the cliff. A portion of the cliff is protected from present erosion by a raised beach whose seaward margin is a steep bank rising 10 to 15 feet above the present beach.

About ten miles farther north there is a mountain range several thousand feet high. The gently undulating plain which, near the sea-cliff, is beyond doubt a glacial plain, extends inland to the foot of this range and a smooth slope extends thence to about midway of the height of the range where it appears, in a distant view, to terminate abruptly along a line which gently rises and falls, suggesting the upper limit of glaciation. Some low ranges of hills that would be included in the glaciated area have rather smooth topography but no features which of themselves would suggest glaciation.

On the northern border of the Kobuk Delta there are in places low bluffs produced by the most northerly channel of the river swinging into a gently undulating upland. Some of this upland country occurs southwest of the mouth of this channel and is bordered by a sea-cliff on the Hotham Inlet side. I did not land at any of these bluffs and cliffs but, seen from a boat, they appear to consist of a thick bed of brown and gray sandy silt like that over the till in the peninsula, but varying to portions much more largely of sand. The rolling plain topography characterizes the lower Kobuk Valley above the delta and the country between the delta and the mountains to the north. Indeed, as far east as I have been, namely, to the Shungnak River, outside of the modern alluvial plain in which the river winds about, the valley floor is everywhere an undulating plain rising from 30 to 200 feet above the river. In the lower valley this plain appears to

consist chiefly of silt, but farther east the ridges seem to be generally of coarser material, either modified drift (water-deposited sand and gravel) or of till. I did not often land at exposures of the latter, but the appearance of bluff faces at many places suggests it. I have no doubt that a careful study of this valley would bring to light moraines both terminal and lateral, but the rolling ground moraine seems to be the predominant feature of this drift.

The first decisive evidence of glaciation seen in ascending the Kobuk River is in a 150-foot bluff on the north side of the river below Squirrel River. As seen from a boat, the bluff appears to consist largely of a blue-gray stony clay, at one place resting on bed-rock. I landed at the Eskimo village at the mouth of Squirrel River and found blue-gray till exposed in the bluff. It abounds in striated stones, including a beautifully glaciated 6-foot boulder. The bank also contains much sand, probably modified drift. The north bank of the river, at a point at which I landed probably about midway between the Hunt and Ambler rivers, consists of a very stony till abounding in scratched pebbles. The country back of it has a morainic topography.

In the "Sketch Map of Alaska Showing Glacial Geology" in "The Geography and Geology of Alaska," etc., by Brooks,[1] published in 1906, the glaciated territory of the Endicott Mountain area is represented as terminating westward at about the mouth of the Ambler River, 173 miles above the mouth of the Kobuk River, and about 130 miles in a direct line from the drift near the mission on the peninsula. This is obviously an error. I traveled in the mountains near the Shungnak River, well within the reputed limit of glaciation, and while I recognized evidences of glaciation there, these evidences were not as pronounced in character as much that I saw in the lower Kobuk and Hotham Inlet regions. Similarly, on Seward Peninsula, I found in 1906 evidences of a more extensive glaciation than had been mapped by the U. S. Geological Survey in its preliminary work. I do not think that there was a general glaciation of northwestern Alaska, but that many of the valleys were occupied by glaciers that ran farther than has been indicated on the map mentioned above.

The Kobuk glacier probably occupied the entire Kobuk Valley. It may have been 230 miles long and 15 to 30 miles wide. It was

[1] U. S. Geological Survey Publications, *Professional Paper*, *No. 45*, Pl. XXII.

probably fed chiefly from the tributary glaciers on the southern slope of the Endicott range. The limestone, schist, and vein quartz drift on the north shore of Hotham Inlet was probably dragged from the hills on the north side of the Kobuk Valley (which are known to be made up largely of such rocks); the gabbroic drift of the peninsula probably was secured in the Hotham Peak range lying south of the Kobuk Valley. If there has been no important change in the relation between land and sea, the Kobuk glacier entered the Arctic Ocean.

BERKELEY, CAL.
April 17, 1908

REVIEWS

The Ann Arbor (Michigan) Folio. BY FRANK LEVERETT. 15 folio pages of text and 3 maps. U. S. Geol. Surv., 1908. *Geologische Streifzüge in Heidelbergs Umgebung.* Von Dr. Julius Ruska. Eine Einführung in die Hauptfragen der Geologie auf Grund der Bildungsgeschichte des oberrheinischen Gebirgssystems. Pp. xi and 208 with numerous original views, maps, and sections. Nägele, Leipzig, 1908.

How often has the university professor felt the need of a convenient printed discussion of essentially local geological problems to which he can refer the student—something not too brief or so diluted as to distort the facts, but an adequate and readable presentation which the earnest student may turn to as a guide. In America this want has in a few instances been met by the geological folio of the university district, and whatever may be said of this form of publication with its endless duplications as applied wholesale throughout the country, it cannot be denied that as an aid to geological instruction at universities through description of the local geology it meets a real need.

The Ann Arbor folio and the German booklet referred to above are alike successful efforts in the direction indicated; the one for a great American university, the other for the oldest German university and the one which many American geologists claim as a second *alma mater*.

The American publication has the luxurious dress of its class, but suffers from its ungainly proportions, particularly when it is carried into the field. Its mechanical construction, while an aid to ready reference, detracts somewhat from the interest of perusal. Fortunately in this instance a most serious objection to the folio system—the patchwork truncation of the area by the accidents of quadrangle limits—is not serious, since Ann Arbor falls almost exactly in the center of the sheet.

The geological interest in the area is very largely restricted to the glacial and post-glacial history, and the significant distribution of the drift deposits with their modification in lake shores, has here been treated by one of our best authorities in that field. The whole subject of post-Wisconsin lake history, as applied to the Michigan area, is here for the first time comprehensively treated in an easily accessible publication. Excellent original

maps serve to set forth in sequence the many stages in this history, including that of the newly discovered Lake Arkona.

The book by Professor Ruska of Heidelberg is an initial attempt to meet a like demand at the German university. Dr. Ruska has the gift of literary style and the ability to present his subject in attractive form without loss of scientific accuracy. Different geological formations and significant surface features come each in turn under discussion in connection with well-planned excursions from Heidelberg. No less than 138 illustrations, many of them original and all well chosen, make the eye the pathway to the mind. Professor Ruska not only knows his field, but he has shown excellent judgment in selecting and arranging his material. W. H. H.

Rocks and Rock Minerals. By LOUIS V. PIRSSON, Professor of Physical Geology, Yale University. 12mo, pp. 414. New York: John Wiley & Sons, 1908.

The new petrology by Professor Pirsson is a volume whose merits are more fully appreciated when one considers the difficulties inherent in the subject, not the least of which is that of classification. If it be remembered that the early and simple classifications based on megascopic characters have gradually become more and more complicated as microscopical investigations progressed until at present they cannot be satisfactorily used without the microscope, it may be admitted that a simplified classification for field work and similar uses has become extremely desirable. The classification adopted in the new work is essentially the same as the "field classification" first proposed in connection with the Quantitative Classification of Igneous Rocks, of Cross, Iddings, Pirsson, and Washington in 1903. On this basis Pirsson has succeeded in presenting in attractive style not merely the major facts of petrology, but also an excellent description of those things which give the science life and human interest. Thus, he not only defines a given rock from every point of view, but he describes its mode of occurrence, its alteration products, its various uses, and, frequently, its relation to ore deposits.

The book is, of course, not adapted to the needs of the geologist and petrographer, but to those of engineering and general students whose knowledge of the subject need not be profound. It is arranged in three parts: an introductory part of twenty pages dealing with the scope, history, and methods of petrology, and the chemical character of the earth's crust: a second part of 112 pages describing briefly the rock-forming minerals and giving short tables for their determination; and the main part dealing with igneous, sedimentary, and metamorphic rocks successively, and closing

with a short table for determining rocks. The illustrations are numerous and remarkably well chosen.

In discussing the origin of the porphyritic texture in igneous rocks Pirsson expresses the current view among petrographers in declaring that the idea of a change in the rate of solidification (for example, intratelluric and extratelluric crystallization) is not an adequate explanation of all occurrences. But it seems to the writer that the labile and metastable states proposed by Miers and indorsed by Pirsson as an explanation of the porphyritic texture are equally unsatisfactory. It seems to merely give names to certain conditions or states in magmas which may produce the texture, without explaining anything. Why such conditions should exist in some cases and not in others—in fact, why they should exist at all—is not clear. The writer would suggest that if we admit the existence of eutectics in igneous rocks (and Pirsson appeals to them to explain salic border zones) we have in their laws a reasonable explanation of the porphyritic texture. Thus, it is well known that any constituent present in a solution in greater amount than the eutectic proportion will begin to crystallize at a temperature above that required for the solidification of the eutectic itself, and will continue to crystallize until the cooling reaches that temperature; then the eutectic will crystallize at that temperature. It is clear then that with a uniform rate of cooling this process will give a much longer period of crystallization to the minerals in excess of the eutectic proportion than to the eutectic itself. This longer period of crystallization would naturally result commonly in larger crystals, that is, the porphyritic texture. In this connection it might be mentioned that Pirsson's statement on p. 171 that "the substance in greatest excess, the solvent, will solidify first" is quite misleading, since the substance in greatest excess is not necessarily the solvent nor the first thing to solidify.

Other minor errors include the crediting of tests of Wisconsin granites (p. 209) to Bain instead of to Buckley, and the omission of silicon in the paragraph on the elements of geological importance (p. 19). On p. 135 Pirsson defines as "hade" and "trend" what are ordinarily called dip and strike. It is not clear that anything is gained by the change, and it must result in some confusion. On the other hand he draws the distinction (p. 158) sharply and well between textures and structures in rocks, and describes numerous examples of each. His discussions of the difficult subjects of metamorphism, differentiation, etc., are remarkably well adapted in their simplicity and clearness to the place they occupy. As is to be expected, they reflect chiefly the views of the German school of petrographers.

A. N. W.

The Fairbanks and Rampart Quadrangles, Yukon-Tanana Region, Alaska. By L. M. Prindle Bulletin 337, U. S. Geological Survey.

Geology and Mineral Resources of the Controller Bay Region, Alaska. By G. C. Martin. Bulletin 335, U. S Geological Survey.

Mineral Resources of Alaska, 1907. By A. H Brooks and others, Bulletin 345, U. S. Geological Survey.

Following the policy of the Alaska Division of the United States Geological Survey of getting the results of its investigations before the public as soon as possible, the first bulletin is a concise summary of the present knowledge of the geology of the area covered by the topographic maps and issued at the time of their completion. Papers by G. C. Covert on the water resources of the Fairbanks region and the Rampart gold placer region by F. L. Hess are also included.

The second bulletin, on the other hand, is a detailed study of the coal-bearing rocks occurring in the area about Controller Bay and is a final report as far as is possible with the slight amount of development that has been done in the area. The age of the rocks is determined to be Miocene, with a possibility of the base of the series extending down into Oligocene. The rocks have been greatly disturbed and exact correlation made difficult by the lack of good exposures together with the present hazy state of our knowledge of the Tertiary of the Pacific Coast. Several terraces and benches indicate extensive recent elevation.

In the last bulletin is found the administrative report by A. H. Brooks, chief of the Alaska Division, together with several short papers by various members of the division summarizing present knowledge as to the occurrence and development of deposits of gold, copper, tin, coal, building-stone, and marble, together with papers on the methods of prospecting and mining, and the water supplies of the principal camps.

J. C. J.

The Iron Ores of the Iron Spring District, Southern Utah By C. K. Leith and E. C. Harder Bulletin 338, U. S. Geological Survey.

This bulletin describes a small area in the southwestern corner of Utah, about 250 miles south of Salt Lake City. Sedimentary rocks of Carboniferous, Cretaceous, and Tertiary age have been intruded by large masses of andesite that are possibly laccoliths, and, after erosion, subsequent lava-

flows have covered the region. Later erosion has partly uncovered the older sediments and intrusives.

The ores are principally magnetite and hematite with a small amount of limonite, and occur (*a*) as fissure veins in the andesite, (*b*) as fissure veins and replacement deposits along the contact of the andesite and limestone, and (*c*) as a cement in a Cretaceous quartzite-breccia.

J. C. J.

Geology of the Rangeley Oil District, Colorado. By Hoyt S. Gale. Bulletin 350, U. S. Geological Survey.

A small field at the western border of Colorado is described where considerable prospecting for oil has been going on with some success. The rocks are principally Cretaceous and Tertiary. The base of the Wasatch formation (Tertiary) rests with apparent conformity upon the top of the Mesaverde formation (Cretaceous), but the absence of formations found between them elsewhere in Colorado indicates a non-conformity here. The structure is a quaquaversal fold with little evidence of faulting. The oil occurs presumably in lenses in the Mancos (Cretaceous) shale.

J. C. J.

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PRINCIPLES OF CLASSIFICATION AND CORRELATION OF THE PRE-CAMBRIAN ROCKS[1]

I

CHARLES RICHARD VAN HISE

A half-hour summary of the principles of classification and correlation of the pre-Cambrian rocks can give no more than the barest outline of the subject.

In the classification and correlation of the pre-Cambrian formations we lack the guide of fossils. While life existed in pre-Cambrian times, and a few fossils are found in several areas, they are not sufficiently abundant to serve either for the purposes of classification or correlation. How far-reaching this handicap is will be realized when this paper is contrasted with those that follow. In considering the questions of classification and correlation of the later formations, fossils occupy a paramount position. It is true that the faunal breaks are often and probably are generally dependent upon physical causes, and the latter are frequently considered; but when the determinations are made, the fauna rather than the physical factors are given first place.

In the classification and correlation of the pre-Cambrian our sole criteria are physical. Therefore we have for the discriminations only those guides which for the fossiliferous rocks are commonly regarded as subordinate. It follows that with the pre-Cambrian rocks we are on less certain ground than with the later formations. However,

[1] Read before Section E of the American Association for the Advancement of Science, December, 1908.

the very fact that fossils are not available in studying the pre-Cambrian has led the workers in this field to a careful consideration of the physical criteria and their relative value.

Among the physical factors which have been used in the classification and correlation of the pre-Cambrian, the following are the more important: (1) Lithological character; (2) Continuity of formations; (3) Likeness of formations; (4) Like sequence of formations; (5) Subaerial or subaqueous deposits; (6) Unconformities; (7) Relations to series of known age; (8) Relations with intrusive rocks; (9) Amount of deformation; (10) Degree of metamorphism.

1. *Lithological character.*—The first step in the study of rocks from a physical point of view is to determine the character of the formations, series, and groups—whether igneous or sedimentary; if igneous, whether plutonic or volcanic, acid or basic; if sedimentary, whether psephite, psammite, pelite, limestone. While according to definition a formation is essentially a lithological unit, usually this unit is more or less composite, consisting of many somewhat variable beds and often of several members of different character. Because of the variability of the elements constituting a formation, there are an indefinite number of permutations and combinations of these factors. This results in giving a given formation, series, or group special peculiarities which often enable one to recognize it even when actual connections of the various outcrops have not been observed.

Accepting any of the current theories as to the history of the earth, the rocks of the earliest time are dominantly of igneous origin, and those of later time dominantly sedimentary. Since the earliest Cambrian rocks contain remains of all the great types of life, it is certain that antecedent to this time the more fundamental and greater part of organic evolution took place. Hence in a full pre-Cambrian succession we should expect the rocks of the early pre-Cambrian to be dominantly igneous and those of the later pre-Cambrian to be dominantly sedimentary. In accordance with the natural expectation, in practically all of the great regions of the world in which the pre-Cambrian have very extensive exposures, and in which close studies have been made, we find that the basal series of rocks is dominantly igneous, and the superior series dominantly sedimentary.

2. *Continuity of formations.*—Where formations in different districts are found to be continuous, they are supposed to be of the same age. It is realized that this conclusion is not absolute, for in the case of a great slanting transgression of the sea, the basal clastic deposits of the early part of the transgression may be considerably earlier than those in the later part, although the formations may be continuous. However, as yet given pre-Cambrian formations have not been traced to sufficiently great distances to introduce important errors upon this account.

3. *Likeness of formations.*—Where in different districts there are like formations, this is of assistance in correlation. Thus, if in several districts of a geological province but a single limestone formation is observed in any one, and the limestone of the different districts has the same peculiarities, there is a natural tendency to suppose all the limestone to be part of a single formation. However, the criterion of lithological likeness alone is not sufficient to establish identity. This is illustrated by the three iron-bearing formations of the Lake Superior region. Because these formations were of such an exceptional and peculiar character, and were so remarkably alike, it was supposed for a long time that they were of the same age. For a number of years this mistaken belief was a serious hindrance to an understanding of the succession and structure in this region. The weakness of lithological likeness in correlation is due to the fact that the same set of physical conditions has frequently occurred during geological time, and thus formations practically identical even in the combinations of their variations, including color, banding, nature of beds, etc., have been produced again and again.

4. *Like sequence of formations.*—Similar sets of formations in the same order furnish a criterion for correlation, of much greater consequence than the likeness of a single formation. But even this criterion has severe limitations, for similar sets of formations in the same order may have been deposited a number of times during a geological era; for instance, when a sea transgresses over a land area there are normally formed in order a psephite, a psammite, a pelite, and a non-clastic formation, and frequently over this, another pelite. Several such similar sets of formations are known in the pre-Cambrian in a single geological province.

5. *Subaerial or subaqueous deposits.*—Closely connected with the third and fourth criteria is the question as to whether the deposits were laid down under air or under water. It is clear that the conditions of deposition of these two classes of rocks are so different and the nature of the formations which may be contemporaneous so variable, that there is great difficulty in correlating the two. Also it is plain that the difficulties in correlating disconnected continental deposits are scarcely less great. Only recently has serious study been undertaken to discriminate subaerial and subaqueous deposits. This subject will not be gone into here, since it is one which has been recently discussed in several extended papers. I may, however, speak of one point. So far as we can yet determine the subaerial deposits are in general not so well assorted nor so likely to be sharply separated into distinct formations as the subaqueous deposits. This statement is believed to hold although it appears that under exceptionally favorable conditions the aerial deposits may be pure quartzose sands. Consequently cleanly assorted quartzose sands, pure limestones, and series composed of sharply contrasted formations are regarded as strongly favoring the idea of subaqueous deposition. As yet there is no evidence that air has the discriminating capacity which water has in producing cleanly assorted sands. If it is difficult to discriminate subaerial or subaqueous deposits, it is much more difficult to discriminate subaqueous deposits of the inland lakes and seas from those of the ocean.

6. *Unconformities.*—Unconformities are of great assistance in classification and correlation. It has been intimated that the great physical movements producing unconformities are frequently the real causes of faunal changes. Irving was the first fully to realize the importance of unconformities in correlation. The criteria by which unconformities are determined and their magnitude and significance analyzed cannot be discussed in a short paper. Those interested in this aspect of the subject must be referred to the original discussions.[1]

It should be remarked, however, that unconformities may have

[1] Roland Duer Irving, "On the Classification of the Early Cambrian and Pre-Cambrian Formations," *Seventh Annual Report*, U. S. G. S., pp. 365–454; Charles Richard Van Hise, "Principles of North American Pre-Cambrian Geology," *Sixteenth Annual Report*, U. S. G. S., pp. 724–34.

a very variable extent and significance. It is now realized that a sharp orogenic movement may take place resulting in uplift, erosion, subsidence, and therefore discordance of strata, which may not affect an adjacent area. Thus it should clearly be understood that it cannot be assumed that unconformities due to orogenic movements are more than of district extent. There are, however, great movements of uplift and subsidence which are continental and may be even intercontinental. Unconformities due to movements of this kind may have a very wide extent, and may thus be used for correlation from province to province, or possibly even from continent to continent. But in order that this may be fully done, it is necessary to show that the unconformity upon which correlation is based is an extensive one.

As yet insufficient careful study has been made of known unconformities from this point of view. Here is a great and fundamental field for investigation. If the known unconformities of the world were broadly studied, it is probable that many can be determined to be local, others to be provincial, others continental, and a few intercontinental. No more important determination than this remains to be made in geology. So far as I can see until this work is done there will be no very close correlation of pre-Cambrian formations from province to province and from continent to continent.

7. *Relations to series of known age.*—The relations of a formation, series, or group, to other formations, series, and groups of known age are of very great assistance in correlation. Frequently a formation, series, or group may be continuous or recognizable in the different districts of a geological province when other formations, series, or groups are not continuous. The position of the latter with relation to the former, whether above or below, and if above or below, conformable or unconformable, are valuable helps in correlation. Thus the Keweenawan is practically continuous about the entire Lake Superior basin. This is the only series of which this is true. The position of the series called Upper Huronian immediately but unconformably below the Keweenawan in different districts in connection with other facts is of great significance.

8. *Relations with intrusive rocks.*—The older is a series the more intricately is it likely to be cut by intrusive rocks, and this relation is of assistance in correlation in connection with other criteria. If a

series is intricately cut by igneous rocks, all of which stop at a definite horizon, this is strong evidence that the adjacent rocks free from such intrusives are later and probably belong to a different series.

9. *Amount of deformation.*—The amount and nature of the deformation are of assistance in correlation within limited areas. Upon the whole, the older a series the greater and more intricate the deformation. The difference in the amount of deformation in the pre-Cambrian series wherever there is a somewhat full succession of formations is sufficiently great to make this an important factor in the classification and correlation of the formation.

10. *Degree of metamorphism.*—The amount of metamorphism is a factor in correlation. Upon the whole, the older a series the more likely it is to be metamorphosed, but this criterion has severe limitations, since within comparatively short distances the closeness of folding and the quantity of intrusives may greatly vary, and these are very important factors in metamorphism. The worker among the pre-Cambrian rocks must have a very thorough understanding of the principles of metamorphism and the nature of the transformations through which rocks go. For, in working out the stratigraphy of the pre-Cambrian, if the criterion of the original character is to be used, it is necessary to know the rocks which the now greatly metamorphosed varieties represent.

GENERAL STATEMENT

In actually working out the succession of formations, series, and groups in the different districts of a geological province and in correlating them, all of the above criteria must be used. It is in judgment in appreciating the value of each of these criteria and their combinations that the skill of the pre-Cambrian stratigraphical geologist appears.

To this time, from my point of view, the only divisions of the pre-Cambrian which have been proved to be general, if not world-wide, are those of the Archean and the Algonkian. This subject I shall not take up in detail, since I have recently discussed it in another address.[1]

[1] Charles Richard Van Hise, "The Problems of the Pre-Cambrian," *Bulletin, Geological Society of America*, Vol. XIX, pp. 1–28.

However, it may be said in summary that the Archean is a group dominantly composed of igneous rocks largely volcanic and for extensive areas submarine. Sediments are subordinate. The Algonkian is a series of rocks which is mainly sedimentary. Volcanic rocks are subordinate. The Algonkian sediments where not too greatly metamorphosed are similar in all essential respects to those which occur in the Paleozoic and later periods. When the Algonkian rocks were laid down essentially the present conditions prevailed on the earth. The Archean rocks on the other hand indicate that during this era the dominant agencies were igneous. The physical conditions had not yet become such as to lead widely to the orderly succession of sedimentary rocks like those being formed today. On the whole the deformation and metamorphism of the Archean are much farther advanced than the Algonkian. The two groups are commonly separated by an unconformity which at many localities is of a kind indicating that the physical break is of the first order of importance. As evidence of this, at many places are the fundamental difference in the character of the rocks, the greater intricacy of intrusion, greater deformation and metamorphism of the older group, and deep intervening erosion. In some localities a part of these phenomena are lacking, but the significance of an unconformity is determined by the places where evidences of its magnitude occur rather than where lacking. So profound are the contrasts between the Archean and the Algonkian in each of the great regions of the world in which the pre-Cambrian has been studied, and so similar are each of these great groups with reference to the fundamental principles discussed that it has been regarded as safe to correlate these two groups even when in distant geological provinces. In making this correlation it is not supposed that the formations of one province are of exactly the same age as those of another province, but that the formations assigned to the Archean and Algonkian respectively in any given case belong to the two great eras of the pre-Cambrian represented by the rocks of these groups.

For extensive areas the Archean may be divided into Laurentian and Keewatin. These divisions are purely lithological, the former being mainly plutonic acid igneous rocks and the latter basic igneous rocks, largely volcanic. The Algonkian in many of the various

geological provinces may be divided into two or more series separated by unconformities. The formations of these series are commonly sedimentary, although igneous rocks are often abundant. As a whole, to the Archean group ordinary stratigraphical methods do not apply. To the Algonkian such methods are as applicable as to the Paleozoic and later series.

While the subdivisions of the Archean and of the Algonkian can be frequently equated in the same geological province, as, for instance, in the case of the Upper Huronian in the different districts of the Lake Superior region, it has not been found practicable to equate them from province to province. That is to say, one cannot be certain as to the correspondence of individual Algonkian series of China, Scandinavia, and of the Cordilleran region. If, as above suggested, it becomes possible to work out the physical history of the continents so that it may be determined which of the unconformities are continental, and intercontinental, or if in the pre-Cambrian rocks distinctive faunas are found, then closer correlation of the pre-Cambrian in different geological provinces may be possible than the Archean and Algonkian. In the meantime we must be content with the classification of the pre-Cambrian rocks in different geological provinces into Archean and Algonkian, with the understanding that the formations placed in each of these groups belong in a general way to the two early eras of the earth, during the first of which the agencies were dominantly igneous, and during the second of which the conditions had become similar to those of today. Further, within each geological province the Archean and Algonkian may be divided into series and formations which for each province are given local names.

THE BASIS OF PRE-CAMBRIAN CORRELATION.[1]

II

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That was indeed a fair and sunlit earth which our predecessors, the first geologists, had presented to them for study. The uniform strata of the newer periods of our earth's history in their succession, well exposed, and following one another in due and regular order, everywhere contained abundant fossil remains which afforded a certain clue by which correlation could be made even in widely separated areas. We, their unfortunate successors, in pursuing our studies are obliged to descend into the deeper parts of the earth where the light begins to fail and when once we pass through that last grim portal into the drear pre-Cambrian world, we enter into what these earlier geologists regarded as a hopeless chaos. Here we lose the guiding thread of life, and the darkness deepens. At first we could dimly descry but the outlines of the vast indeterminate ruins of former worlds, but as our eyes become accustomed to the darkness these become somewhat more distinct and we recognize succession even in this ruined waste.

It may be that being a petrographer I overestimate the value of paleontology, but, like other things, we prize it most highly when it is lost and we are obliged to look for something to take its place. The working-out of the stratigraphical succession by detailed mapping in special areas teaches us much, but unfortunately the areas showing such succession are usually limited and isolated and the criteria for correlating the successions in separated areas, and especially in widely separated areas, are as yet undiscovered.

The vice-president of our section, Dr. Bailey Willis, in inviting me to take part in this symposium, has suggested that I should treat this subject of pre-Cambrian correlation if possible on broad lines, and I therefore venture today to follow Faust's aspiration, "Schau' alle Wirkenskraft und Samen," and present a certain aspect of the

[1] Read before Section E of the American Association for the Advancement of Science, December, 1908.

subject which I hope may at least be suggestive of a line along which some advance may be made in the correlation of these ancient rocks.

In his *Research in China* (Vol. II, chap. viii) Dr. Bailey Willis has put forward a theory to account for the origin of continental structure. In each of our present continents there are areas which during the evolution of the continent have always tended to rise—these he calls *positive* elements. There are certain other areas which have always shown a tendency to sink, relatively to the adjacent masses—these he calls *negative* elements. The movement of these elements is due to the greater relative density of the negative elements causing them to sink, while the relatively lighter positive elements tend to rise so as to bring about an isostatic adjustment. There have been horizontal movements as well as those in a vertical direction. These are of notable magnitude and their effects are seen in the schistose structure of these once deep-seated rocks and the overthrust and folded structures of the more superficial strata. The tendency toward vertical displacement has actually resulted in movement only at long intervals and during relatively short periods. Hence we may recognize cycles of diastrophism each one of which comprises (a) a comparatively brief period of orogenic and epeirogenic activity which results in elevated lands and restricted mediterranea; and (b) a comparatively long period of continental stability, which results in extensive peneplanation. The critical times which bring out continental structure are the epochs of diastrophic activity. During periods of inactivity the distinction between the positive and negative elements becomes less obvious and may even become obscured by extended peneplanation and marine transgression.

In a subsequent paper,[1] the same writer outlines the positive and negative elements of the continent of North America. The Canadian Shield, which is also called *Laurentia*, is at once the largest and the most readily distinguished positive element of the continent. It has an area of approximately two million square miles and the true boundary may be traced along the St. Lawrence Valley into the deep of Baffin's Bay and then north of the Arctic Archipelago (which is scarcely to be separated from Greenland) across the Arctic Ocean

[1] Bailey Willis, "A Theory of Continental Structure Applied to North America," *Bull. Geol. Soc. of America*, Vol. XVIII, p. 392.

and back to the mouth of the Mackenzie. Beneath the Cretaceous of western Canada, the margin of this element lies hidden. It ranges past Lake Winnipeg toward the state of Wisconsin, and then follows the shore of the Paleozoic mediterranean east to the Adirondacks and St. Lawrence.

Now it would seem, if we select a single positive element such as Laurentia—remembering that the critical diastrophic periods will be short and the intervening periods of deposition and accumulation will be of long duration—that these epochs of diastrophism, with their development of schistose structure in the moving masses and the associated phenomena of igneous intrusion, might be employed as a basis for the subdivision of Proterozoic time, and if the element moved as a whole, might even serve as a basis of correlation over the whole vast area. Laurentia, however, has not as yet been studied geologically except in a general way. Its detailed study will supply problems for generations of geologists yet unborn. Its southern margin alone, and that only in a few comparatively small areas, has been mapped in detail, but nevertheless exploratory and reconnaissance work has been carried out over almost the whole of the great expanse of this ancient continent chiefly by the officers of the Geological Survey of Canada, so that we have a good general knowledge of the main outlines, at least, of its geological history. It is proposed here to present a general statement of the results obtained, as they bear upon the history of Laurentia in pre-Cambrian times and afford a basis for pre-Cambrian correlation, making use of this principle of critical diastrophic epochs and drawing evidence from the area as a whole, rather than from a few restricted areas on its southern border.

This task is rendered comparatively easy owing to the fact that a critical digest of the mass of information concerning the pre-Cambrian rocks of the great central and northern portions of Laurentia, which is found disseminated through the reports and papers by the various geologists who have worked in this great area, has recently been prepared by Dr. George A. Young, of the Geological Survey of Canada, who has himself traveled very extensively in this northern country. I am indebted to Dr. Young for permission to make use of this unpublished material, but the original papers have been consulted in the case of all the more important occurrences.

The great expanse of Laurentia is underlain predominantly by the rocks of the Laurentian system. These consist of gneisses in infinite variety which in the majority of cases have the mineralogical composition of granite, although some present foliated varieties of rocks ranging from syenite to diorite. The foliation is in some cases so faint that it can be detected only on large weathered surfaces, but generally it is quite distinct or even striking. In addition to the foliation the rock often displays a very distinct banding due to the alternation of varieties of diverse character or composition. This foliation is in many, and possibly in the majority of cases, a primary structure and the darker bands very frequently represent included masses of overlying rocks, softened and in some instances partially digested. This foliation and banding was at one time regarded as a partially obliterated bedding and considered to present indisputable evidence that the rocks were of sedimentary origin. These gneissic rocks are not all of the same age, for frequently one mass can be seen to cut another. In addition to these gneissic granites, syenites, and diorites, however, the Laurentian comprises other kinds of plutonic rocks of very diverse character. Thus, from Minnesota to the shores of Ungava Bay, intrusions of anorthosite are found. Several of these, for the most part distributed along the margin of the protaxis in the province of Quebec and in the Ungava peninsula, present areas of from a few miles to 10,000 square miles in extent, and represent some of the more recent pre-Cambrian plutonics, although they themselves have been cut by still later granites. In fact, it is becoming more and more evident with the progress of geological investigation that the Laurentian is a vast complex of plutonic rocks of widely varying types and differing greatly in age, although there is no evidence to show that any of them were intruded later than the close of the Proterozoic. Whether in this enormously extended complex, which we term the Laurentian in the northern protaxis, there still survive any primitive sediments or any portion of an original crust, through which these great bodies of intrusive rocks forced themselves, is unknown. None have as yet been distinguished with certainty, but if any do exist they are probably similar in composition to these earliest intrusive rocks and might easily escape notice.

It is certain, however, that the overlying Keewatin and Grenville

series were deposited on some floor, although this floor has remained undiscovered up to the present time. Either the Laurentian gneiss, or some part of it, represents the original floor, subsequently melted and intruded into the overlying sediments, or the original floor remains unrecognized among the enormous bodies of intrusive rocks which resemble it in character.

Resting on this Laurentian complex, in the region of the Great Lakes, although penetrated by it, the lowest sedimentary series here recognized is the Keewatin series, a great body of rocks largely of pyroclastic origin, but in some districts containing great thicknesses of epiclastic material.

It is not necessary here to make further reference to this great series which has been so well described by so many writers. In this region it is the oldest sedimentary rock recognizable as such.

In the region of the St. Lawrence Valley this Keewatin is not seen, but there is a series of extraordinary thickness and enormous areal extent composed essentially of limestones, which rocks are practically absent in the Keewatin. Whether this series, known as the Grenville series, is the equivalent of the Keewatin is unknown as yet. If it be, the designation of the Keewatin by Van Hise as a series composed essentially of pyroclastic material to which stratigraphic methods cannot be applied and the assumption that such material characterized the earliest stratified deposits of the earth's history, must be abandoned, for the Grenville series is distinctly stratified and is one of the greatest limestones series in the earth's crust. However that may be, these two series constitute the oldest sediments in the earth's crust recognizable as such in their respective districts. Similar rocks apparently characterize extensive areas in the more northern and remote portions of Laurentia representing the oldest recognizable sediments in these districts.

At the close of this first period of long-continued sedimentation there came an epoch of diastrophism—a thrust exerted from a south-easterly direction against the ancient continent threw these series into a succession of great folds running approximately parallel to the present valley of the St. Lawrence. Enormous bodies of granitic magma rose in great bathyliths along the axes of the folds, disintegrating, fraying out, metamorphosing and partially absorbing the

lower surfaces of the invaded sediments. Everywhere over thousands of square miles these ancient sedimentary rocks can be seen to have floated on the granite magma or to have been sunk into it and to have been cut to pieces by apophyses of it. That these movements were, in many cases at least, very slow, is shown by the fact that a study of the primary gneissic structure displayed by the bathyliths demonstrates that the upward movement of the latter began before crystallization had set in and continued while the magma was slowly filling with the products of crystallization and until it finally froze into a solid rock. This epoch of diastrophism, resulting in the elevation of great tracts of country, brings to a close the first clearly recognizable chapter in the history of Laurentia.

After prolonged and profound denudation the sea again transgressed upon the continent of Laurentia and in this sea were laid down the strata of the earlier Huronian time. The sea at this time passed over what is now the region of the Great Lakes and extended at least as far north as Lake Mistassini and as far west of the head of Lake Winnipeg. Locally it evidently extended as far inland as the latitude of the northern end of Hudson Bay. Within this earlier Huronian time there was, following the deposition of the Lower Huronian, a period of subordinate elevation and depression in the district of the Great Lakes marked by the deposition of the Middle Huronian. At the close of this period of deposition, there was again an epoch of widely extended diastrophism due to a thrust exerted upon the southern portion of the continent from the ocean bed to the southeast and resulting in the widespread folding of the sediments which had been deposited over the southern portion of the protaxis, into a series of mountain ranges running in a northeasterly to southwesterly direction, with accompanying metamorphism of the folded strata and deep-seated intrusion of vast amounts of igneous rock. It may be that the great body of sediments forming the Grenville series really belongs to this rather than to the earlier Keewatin period, but be that as it may, these great orogenic movements which took place at the close of the earlier (Lower and Middle) Huronian time, brought to a close the second great chapter in the pre-Cambrian history of Laurentia.

There then followed a period of deep and long-continued erosion, during which the Lower and Middle Huronian and the underlying

sedimentaries were swept away over the greater part of the region, leaving only the lower portion of the folds—the roots of the mountains —in the form of long narrow belts, separated by the granitic rocks marking the axes of the intervening anticlinal uplifts. This period of profound erosion constitutes what Lawson has termed the Eparchean Interval. Up to this time the movements which affected the continent of Laurentia were due, as has been stated, to thrusts coming from the southeast and caused by the negative element underlying the Paleozoic plain in this direction, at that time constituting the ocean bed, by its subsidence crowding against the positive element which formed the continent of Laurentia. This is seen, as has been stated, in the distribution of the older rocks of the first two chapters of the pre-Cambrian in the form of long narrow belts running in a general northeasterly and southwesterly direction and representing the downward sagging portions of the ancient folds.

Succeeding this long period of intense and widespread erosion, which followed upon the conclusion of Middle Huronian or pre-Animikie time, there was again a very widespread transgression of the sea upon the surface of the continent of Laurentia. In this was laid down a series of sediments which while occurring at localities sometimes separated from one another by hundreds of miles, yet preserve the same general features. These younger rocks form chains of islands fringing the east coast of Hudson Bay over a distance of about three hundred miles and have been described under the title of the Nastapoka series. This assemblage of beds dips toward Hudson Bay, generally at low angles, and lies in long parallel ridges with steep eastern faces. The strata comprise a group of arkoses and sandstones overlain by sandstones, argillites, cherty limestones and dolomites and calcareous shales with great intrusive sheets of diabase. The series has been found in places to have a thickness of at least three thousand feet and is further characterized by the occurrence at certain horizons of beds of banded jaspilite and iron ores. In the interior of Labrador, where the series dips at low angles toward the Atlantic, there is throughout a zone at least three hundred miles long, a development of similar rocks and here again occur the jaspilite beds. On the Atlantic side, at the head of Hamilton inlet, and further up the river of the same name, occurs a similar series,

while on the Atlantic shores, far north, is found a great group presenting many like features. West of James Bay and south of Hudson Bay, rocks lithologically like the Nastapoka series underlie a hilly district rising like an island above the surrounding flat-lying Paleozoic beds. In this great district of the pre-Cambrian west of Hudson Bay, large areas bordering the Arctic about the mouth of the Coppermine River, and extending to Great Bear Lake, are underlain by a development of rocks resembling in nearly all respects the Nastapoka series and similar rocks have been described from the region about Great Slave Lake.

In all these widely separated localities great developments of the same rocks occur and often are accompanied by beds of jaspilite and iron ore. Everywhere the members present the same general arrangement, the strata cut by many faults, dipping at comparatively low angles and forming ridges frequently capped by diabase, while in most cases the beds have been found overlying with a most striking unconformity older granitic and gneissic rocks. These points of similarity seem to indicate that the scattered groups are all of about the same age and belong to a pre-Cambrian series probably at one time nearly continuous over the northern regions from the shores of the north Atlantic to about the valley of the Mackenzie. In Labrador and in the districts west of Hudson Bay the evidence indicates that the Nastapoka series was deposited after an epoch of severe erosion. Lake Mistassini, in northern Quebec, lies in a basin-like depression occupied by nearly flat-lying beds of cherty dolomite representing a portion of the Nastapoka series, while south of the lake these rocks have been found almost in contact with a development of the Lower (or Middle) Huronian, differing in no essential features from this group of rocks as found in numerous localities further southwest toward Lake Superior. The Lower Huronian is in a highly disturbed condition and has been penetrated by large bodies of granite. Neither the disturbances nor the granitic intrusions have affected the near-lying Nastapoka series so that the latter seems to be undoubtedly of post-Lower (or Middle) Huronian age, to have been formed after the Lower Huronian had been folded and invaded by the granites and then deeply eroded. The relation of the two series resembles that existing between the Animikie and Lower Huro-

nian at Port Arthur, and largely on these grounds the Animikie or Upper Huronian of the Lake Superior region and the Nastapoka series of Labrador and the territories south and west of Hudson Bay been have considered to be equivalent to one another.

The Nastapoka-Animikie series, forming the third major division of the pre-Cambrian in Laurentia, is of great importance, marking as it does one of the most widespread periods of submergence and depression in pre-Cambrian times, involving almost the whole continent of Laurentia. No division of the pre-Cambrian in Laurentia is exposed over such a great area of country. The positive movement which raised these rocks out of the sea was chiefly epeirogenic in character, for over the greater part of this area they still lie nearly flat. That the close of this time was, like those which preceded it, marked by an epoch of diastrophism, is shown by the widespread development of faults, accompanied in places by overthrusting. These are the superficial expression of the movements of deepseated intrusions, representing the last period of pre-Cambrian orogenic action. These post-Animikie granitic intrusions are to be seen on the east coast of Hudson Bay where, while the Nastapoka series in most places lies unconformably on the ancient Laurentian and the associated gneisses and schists, yet at some points it is cut by granitic intrusions.

This epoch of mild diastrophism brought to a close the third great period in the pre-Cambrian history of Laurentia.

The Nastapoka series seems to be the youngest division of the pre-Cambrian now found in the region east of Hudson Bay, but west of this inland sea, in a district bordering the southern shores of Lake Athabasca and stretching over an area of perhaps 24,000 square miles, is a great development of coarse sandstone in thick beds which along the shores of the lake aggregate at least four hundred feet in thickness. These, the Athabasca sandstones, lie in nearly horizontal positions, at times with a conglomerate layer at their base composed of fragments of the Laurentian granites and gneisses on which they rest with a strong unconformity. The Athabasca sandstones, or a very similar series, are exposed for a long distance up the valley which is continued seaward by Chesterfield Inlet, situated far north on the western shores of Hudson Bay. Between Lake Athabasca and the above locality, and in places associated with similar sandstones, are extensive areas

underlain by basic and acid volcanics, porphyrites, and porphyries. These sandstones and volcanic rocks are, by the Canadian survey, classed provisionally as of pre-Cambrian age and it seems not improbable that they are later than the groups of rocks about Great Bear and Great Slave Lakes which have been correlated with the Nastapoka series. Thus it is possible that the Athabasca sandstones and associated volcanics are the northern representatives of the Keweenawan of Lake Superior, concerning whose pre-Cambrian age there is a similar doubt.

These sandstones are composed chiefly of quartz grains which it has been supposed have been largely derived from a series of quartzites known as the Marble Island quartzites and which on the western shores of Hudson Bay occur at intervals over a stretch of about one hundred and twenty miles. These are associated with masses of dark schists, etc., lying in a disturbed condition. The presence of siliceous material in the widespread Athabasca series, so like that composing the quartzites, would seem to indicate that these latter were at one time also widely developed. What their equivalents elsewhere are, if they have any, is not yet known. They apparently are older than both the Athabasca and the Nastapoka series and may belong to some division corresponding to the earlier Huronian.

The rocks of the Athabasca-Keweenawan series are unaltered and lie practically flat. They have not been affected by orogenic disturbances or deep-seated plutonic intrusions. The uplift which raised them from the waters of the ocean was epeirogenic in character. Since the close of the pre-Cambrian, the continent of Laurentia, while preserving its character as a positive element, has undergone many oscillations, but orogenic or mountain-making forces have never manifested themselves, and the successive epeirogenic uplifts have resulted in and to a certain extent been compensated by the deep and long-continued erosion to which the continent has been subjected throughout the greater part of post-Proterozoic time.

Using therefore the epochs of diastrophism, which mark the successive stages in the pre-Cambrian development of the continent, as a basis of correlation, provisionally grouping the Athabasca Sandstones with the Nastapoka series, it would appear that we have three

major periods in the pre-Cambrian history of Laurentia separated by two critical epochs of diastrophism, with possibly a fourth period represented by the Laurentian rocks at the base of the series. That is to say we have three major periods in the pre-Cambrian succession separated by epochs of diastrophism, which diastrophism at each epoch exhausted itself for the time. These are as follows:

Neo-Proterozoic	Keweenawan-Athabasca
	Upper Huronian or Animikie-Nastapoka
Meso-Proterozoic	Middle Huronian
	Lower Huronian
Eo-Proterozoic	Keewatin (Intrusive contact) Laurentian (embracing the original crust, if any remains)

The lines drawn between the several subdivisions indicate unconformities, the heavier lines indicating the major breaks referred to in the text.

If we attempt to make a comparative study of the earlier continental evolution of North America and that of Asia, we note at the outset that the Siberian nucleus is a portion of that northern Polar region which comprises also Russia, Greenland, and Laurentia, against which stress has been continuously exerted by the denser masses of the more southern latitudes. As has been emphasized by Suess, the Siberian nucleus has been undisturbed since a pre-Cambrian date, and the same is essentially true of Laurentia also. We find that in Asia there were in geological time great mediterranea which, after they had been made the basins for the accumulation of great thicknesses of sediment, were successively closed by great thrusts from the south which folded up the sediments into mountain ranges and then converted these into dry land. In Europe the Alpine region was a marine strait in Cretaceous time, which was subsequently converted in this way into a mountain range.

In the North American continent, of which Laurentia forms a part, there seems to have been a somewhat similar sequence in continental development. Thus the Appalachian Mountains and the Cordilleran range of British Columbia represent ancient marine valleys or straits whose sediments are now folded into series of mountain

ranges. The thrusts which closed up these mediterranea and developed mountain ranges from them, were exerted in a northeasterly direction against the southwestern part of the continent, and in a northwesterly direction against the southeastern border of the continent, so that the folds are parallel to the margin of the present continent of Laurentia. If we inquire whether similar long, narrow, belt-like mediterranea existed in Laurentia in pre-Cambrian times, the answer seems to be in the negative. The surface of the continent seems rather to have had upon it at intervals throughout geological time a succession of large, irregular-shaped bodies of water, somewhat resembling the present Hudson's Bay, in which, however, great thicknesses of sediment were accumulated.

The sediments deposited in these bodies of water in Keewatin, Grenville, and the Earlier Huronian times, were folded up into mountain ranges crossing the southern portion of the protaxis in a northeasterly and southwesterly direction, coinciding with the course of the Appalachian folding.

The intense diastrophism which brought to a close the Eo-Proterozoic and again the Meso-Proterozoic time was exerted apparently as far north as the middle of Labrador and the southern portion of Hudson's Bay.

In the later pre-Cambrian mediterranea the Nastapoka-Animikie series and the Athabasca-Keweenawan series were deposited. The almost entire absence of orogenic movement at the close of this time, combined with the great extent and comparatively unaltered character of the rocks, makes the break at the base of the Nastapoka-Animikie series probably the most pronounced in the whole pre-Cambrian succession in Laurentia. Thousands of square miles of practically flat-lying sediments overlie remnants of a highly folded and metamorphosed antecedent series.

We thus have two major breaks in the pre-Cambrian succession, each marked by an epoch of diastrophism which exhausted itself for the time.

An identical series of two major breaks in the Proterozoic succession, marked by epochs of pronounced diastrophism which in each case exhausted itself, is found in the Asiatic portion of the nucleus.

The succession here is as follows:[1]

Neo-Proterozoic...... (Hu-t'o system)......	Tung-yu limestone T'ou-t'sun slates	Slates, limestones and quartzite.
Meso-Proterozoic.....	Si-t'ai series	Chiefly chlorite schist; quartzite conglomerate at the base.
(Wu-t'ai system)......	Nan-t'ai series	Siliceous marble, jasper, quartzite, and schist.
	Shi-toui series	Mica schists, gneiss, magnetite quartize, and basal feldspathic quartzite.
Eo-Proterozoic.......	T'ai-shan complex	Basal complex of varied gneisses and younger intrusions.

The lowest of these series, the T'ai-shan, resembles the Keewatin penetrated by Laurentian intrusions, being

a metamorphic complex, the constituents of which are largely igneous, though perhaps in part sedimentary in origin.[2]

This was brought to a close by a period of intense diastrophism. Suceeding this:

We distinguish with great certainty a great thickness of very early Proterozoic sediments—the Wu-t'ai—which were intensely deformed and metamorphosed during a mid-Proterozoic epoch of orogeny, owing to pressure exerted by the outlying negative elements, and a later Proterozoic series—the Hu-t'o—which represents shore conditions and which was moderately deformed by pressure exerted by the same cause at the close of the Proterozoic.

Applying therefore this criterion of diastrophic epochs to the correlation of the Proterozoic succession of these widely separated portions of the great northern nucleus, we obtain an identical result in both cases—the diastrophic movements seem to have affected the nucleus as a whole.

It would seem that these diastrophic epochs designate certain of the unconformities in the succession both in the Siberian portion of the nucleus and in Laurentia, as major, dominant, and of special importance, and others as subordinate and of minor importance. We thus have indicated a division of the Proterozoic into Eo-, Meso- and Neo-Proterozoic. On this basis of correlation the T'ai-shan corresponds to the Keewatin-Laurentian complex; the Mu-t'ai to the Lower and Middle Huronian, and the Hu-t'o to the Animikie-Nastapoka series.

[1] *Research in China*, Vol. II, p. 4. [2] *Ibid.*, Vol. I, Part I, p. 19.

These major breaks would seem to be as well marked and as important as those which characterize the separation of the Eo-Paleozoic and the Neo-Paleozoic in eastern America, or perhaps as that which brings to a close the Paleozoic succession in Europe.

If, as our knowledge of the pre-Cambrian becomes more complete, the correlation of these rocks over great areas by a time relation to diastrophic epochs proves to be generally applicable, we have a basis of correlation of great value and importance. This will constitute a great advance as compared with our present methods, which afford no adequate means of determining the relative values of unconformities and thus the successions in the most distant parts of the world are now being matched with each other and an unwarranted satisfaction is manifested if the number of unconformities in the pre-Cambrian succession in different continents is approximately identical, and a sure and certain hope that all will prove to be satisfactory is expressed if there is no agreement.

All that we really know at present is that

> there are great sequences of pre-Cambrian sedimentary formations, separated by many gaps from each other, which give one picture, growing less distinct in outline the farther back one goes, of the remotest periods of geological history, or, in other words, of periods of the earth's pre-historic age which is, according to the author's opinion, probably of greater length than all subsequent geological time.[1]

It is believed, however, that through the recognition of these diastrophic epochs, the dominant outlines of these pictures may perhaps be more clearly brought out and the relative values of the different parts thrown into relief in the case of each individual positive element, and that these epochs which have marked the successive stages of advance in Paleozoic and Mesozoic times, may thus be employed with advantage in deciphering the history of the pre-Cambrian as well.

DISCUSSION

CHARLES R. VAN HISE

It is with pleasure that I discuss briefly Dr. Adams' paper, since, allowing for differences of terminology, I find him in nearly complete accord with the

[1] J. J. Sederholm, *Explanatory Notes to Accompany a Geological Sketch Map of Fenno-Scandinavia,* Helsingfors, 1908, p. 31.

United States geologists in reference to the succession and relation of the pre-Cambrian series of Canada. So far as there are differences they will appear below.

The elucidation of the pre-Cambrian succession for the Lake Superior region, which term as here used includes the great tract extending from the Lake of the Woods to north of Lake Huron and south to the Paleozoic rocks, has been the work of many men extending through many years. In 1892, when *Bulletin 86* of the United States Geological Survey, on the Archean and Algonkian appeared, the Lake Superior succession, as now recognized, had been fully worked out,[1] with the exception that what was then called the Lower Huronian has since been found to comprise two series; also the series now called Keewatin was called Mareniscan, but was properly defined. Some years after the publication of this bulletin, Mr. A. E. Seaman discovered the unconformity mentioned in the lower Huronian of the Marquette district. As soon as this discovery was made it was appreciated that the two divisions of the Huronian in the original Huronian area worked out by Pumpelly, Leith, and myself, correspond with the two divisions in the Marquette district. The classification of the pre-Cambrian as thus developed was fully accepted by the International Geological Committee in 1904, and the table giving the succession was published by Leith in 1904, and by the committee in 1905, as follows:[2]

CAMBRIAN
  Upper sandstones, etc., of Lake Superior
    Unconformity
PRE-CAMBRIAN
  Keweenawan (Nipigon)
    Unconformity
  Huronian
    Upper (Animikie)
      Unconformity
    Middle
      Unconformity
    Lower
      Unconformity
  Keewatin
    Eruptive contact
  Laurentian

This succession is repeated by Dr. Adams in his communication, except that the unconformities are omitted, and it is extended to the entire Canadian pre-Cambrian region.

It is indeed gratifying to have completely accepted for the great Canadian pre-Cambrian area the succession which has been worked out for the Lake Superior region, but Dr. Adams implies that his classification rests upon a sounder basis than the same classification offered by others since "drawing evidence from the area as a whole rather than from a few restricted areas on its southern border." But unhappily for the contention of Dr. Adams, it is still true that the Lake Superior region is the only very extensive area in which the detailed geology has

[1] C. R. Van Hise, "Archean and Algonkian," *Bull. 86*, U. S. G. S., p. 195.

[2] *Journal of Geology*, Vol. XIII, p. 104.

been worked out and the full succession given in the table has yet been found. Also when the succession was originally worked out all available information in reference to Canada as a whole was considered and it was suggested that within the regions about Hudson Bay and the Copper Mines Rivers, the equivalents of at least two divisions of the Huronian and of the Keweenawan appeared to be present.[1]

As to the question of a floor for the Keewatin, according to our view, the Keewatin is simply the most ancient series which has been discovered to the present time. Naturally being the oldest series discovered, we have not yet found the rocks upon which it was laid down, and we make no assumption in this matter. Dr. Adams speaks of the Keewatin as a sedimentary series. If he means by this that it is a series laid down at the surface, this characterization is correct. However, we have frequently pointed out that this series is essentially composed of igneous rocks, including both lavas and fragmentals, and is only very subordinately of ordinary sediments.

As to the position of the Grenville series, I hold my opinion in reserve. Miller and Knight have shown that in the Hastings district where the series which Adams places in the Grenville is most extensively developed, there is an unconformity in the sediments. It is their belief that the greater part of the Hastings sediments, including the great limestone of Adams, belongs above this unconformity, below which is the Keewatin. If they are correct in this view, the larger part of the Hastings series included in Adams' Grenville belongs not with the Keewatin but with the Lower or Middle Huronian.

Dr. Adams says in reference to correlation by diastrophism: "This will constitute a great advance as compared with our present methods, which afford no adequate means of determining the relative values of unconformities, and thus the successions in the most distant parts of the world are now being matched with each other and an unwarranted satisfaction is manifested if the number of unconformities in the pre-Cambrian succession in different continents is approximately identical, and a sure and certain hope that all will prove to be satisfactory is expressed if there is no agreement."

In my address before the Geological Society of America a year ago, I introduced the table of pre-Cambrian series for China with their separated unconformities as given by Willis. I remarked that the Lake Superior Algonkian series in their number and their separating unconformities present a remarkable similarity to the Algonkian of China, but said it would "not be well to too strongly emphasize the close correlation suggested." Also I mentioned the "possibility that in the future we may be able to correlate the unconformable series of the Algonkian in provinces separated as far from one another as the Lake Superior region and Northern China."[2]

[1] Charles R. Van Hise, *Bull. 86*, U. S. G. S., pp. 496–502, 1892; *16th Annual Report*, U. S. G. S., Part I, pp. 807–9, 1896.

[2] "The Problem of the pre-Cambrian," *Bull. Geol. Soc. of Am.*, Vol. XIX, p. 26.

Dr. Adams in his paper repeats the quotation from Willis and makes an identical suggestion as to correlation, but implies that this is done upon the basis of diastrophism. Evidently he thinks that there is an "unwarranted satisfaction" in the first case and not in the second.

Each unconformity between any two series of the Canadian region or of China means that between their depositions there has been an epoch of diastrophism and one of erosion. I should be interested to know how the extents and the magnitudes of pre-Cambrian diastrophisms are to be determined except by studying the extents and magnitudes of the unconformities, that is, the extent and amount of the foldings, metamorphisms, erosions, etc., which intervened between the various series. In the paper which I have just read I pointed out that some unconformities are local, some regional, and some probably intercontinental. Adams points out that diastrophism may be regional or intercontinental. Is the distinction between the two greater than difference in language? One we may suggest talks English, the other Esperanto. Evidently if satisfaction is unwarranted in one case it is unwarranted in the other.

I am obliged to dissent altogether from the reasoning in Dr. Adams' paper which makes discriminations as to the magnitudes of the various breaks, upon the basis of Willis's hypothesis of positive and negative continental elements, and upon assumptions as to the sources of the thrusts. Even if these theories be assumed to be correct we do not know that they apply to the North American pre-Cambrian region, for we know nothing of the extent and distribution of the various pre-Cambrian series which are hidden under later rocks. In the western United States where extensive areas of pre-Cambrian protrude through the later rocks, and also in the Mississippi Valley, where are isolated areas of pre-Cambrian, several pre-Cambrian series occur, some of which are probably the equivalent of the series found in the Lake Superior region. Evidently the various pre-Cambrian diastrophic movements cannot be assumed to be limited to the surface areas of pre-Cambrian.

The question of the major groupings of the pre-Cambrian series I shall not attempt to go into in detail, since to do this would result in leaving less emphatic the reality of the accord as to the pre-Cambrian succession which has now come about and which I trust has come to stay between the Canadian and United States geologists, through the acceptance for Canada of the succession mainly worked out in a great area along the southern border of the pre-Cambrian region.

However, I may recall that I fully discussed the major classification of the pre-Cambrian in my presidential address before the Geological Society a year ago, and gave reasons for the primary divisions of the pre-Cambrian into the Archean and Algonkian. In that address I gave objections to a zoic classification, similar to but not identical with that which Dr. Adams adheres to. His proposed major classification is eo-proterozoic, meso-proterozoic, and neoproterozoic. These terms imply that the pre-Cambrian had three distinctive life periods, an *eo*, a *meso*, and a *neo*. This may be the case, but until fossils are

found in the pre-Cambrian in sufficient abundance to justify a zoic classification, there can be no sufficient warrant for proposing that the major divisions of the pre-Cambrian be made upon a zoic basis.

CLOSING DISCUSSION BY THE AUTHOR

The aim of the paper on "The Basis of Pre-Cambrian Correlation" was, as stated, to suggest a method by which it might be found possible to correlate the various subdivisions of the pre-Cambrian rocks over widely extended areas rather than to enter upon a discussion of the classification of the pre-Cambrian of North America.

With regard to this latter classification, however, it must be pointed out that the paper shows that in a general way the classification adopted by the International Committees (United States and Canada) on the "Correlation of the Pre-Cambrian Rocks of the Lake Superior Region" and on the "Pre-Cambrian Rocks of the Adirondack Mountains, the Original Laurentian Area of Canada and Eastern Ontario," probably forms a satisfactory basis upon which the classification of the whole expanse of the great pre-Cambrian development of the Laurentian protaxis can be founded. Professor Van Hise is mistaken in stating that in the paper under discussion the succession recognized by these committees was adopted but that the unconformities were omitted, for in the wall diagram used to illustrate the paper, and upon which the succession of the pre-Cambrian rocks in Laurentia and China was set forth, the unconformities were especially indicated, black lines being used to show those which were of minor importance while broad red lines appropriately emphasized the major breaks in the succession. The unconformities and their relative importance are also shown in the text of the paper. In fact, this is the crucial point of the paper so far as Laurentia is concerned.

Professor Van Hise has insisted, in a long series of papers, that in the pre-Cambrian succession of North America there is one break which in importance far transcends all others, namely, that at the close of the Keewatin. Professor Lawson, however, has insisted that in this succession the chief break lies at quite a different horizon, namely, at the base of the Animikie.

The International Committees, while recognizing the succession of the various elements of the pre-Cambrian, absolutely declined to commit themselves to any opinion as to the relative magnitude or importance of the several unconformities which they recognized.

A study of all the work—much of it recent—which has been done in the more northern portion of Canada indicates that Professor Lawson's break—the Eparchaean Interval as he terms it—is one of the greatest unconformities in the whole pre-Cambrian succession of Laurentia, and probably quite as important, if not more so, than the break at the close of the Keewatin, and that the pre-Cambrian rocks are represented, not by two great systems entirely distinct and separated from one another, but by three great systems.

In Professor Van Hise's presidential address he has referred to the succession of the pre-Cambrian rocks in Scotland, Finland, and China as determined by Geikie, Sederholm, and Bailey Willis, respectively, and notwithstanding the fact that in these successions from one to six unconformities exist, he has in each case selected one unconformity as of paramount importance, and correlating this with the break at the summit of the Keewatin in North America, has held that these various successions support a dual division of the pre-Cambrian rocks which he has maintained to be world-wide. He closes his address as follows: "I wish to express my firm belief that the dual division of the pre-Cambrian into two great groups of rocks [Archaean and Algonkian] seems now as firmly established as the division between any other two groups." I feel, as stated in the paper, that in this conclusion an "unwarranted satisfaction" is expressed.

To sum up, therefore, it seems that the division of the pre-Cambrian rocks of Laurentia into two great major divisions—Archaean and Algonkian—is not supported by the facts in our possession. The pre-Cambrian succession is apparently rather threefold, which three divisions may, for convenience, best be designated as Lower, Middle, and Upper (Eo- Meso- Neo-) Proterozoic, quite independent of any consideration of the presence or absence of life.

THE PROBABILITY OF LARGE METEORITES HAVING FALLEN UPON THE EARTH

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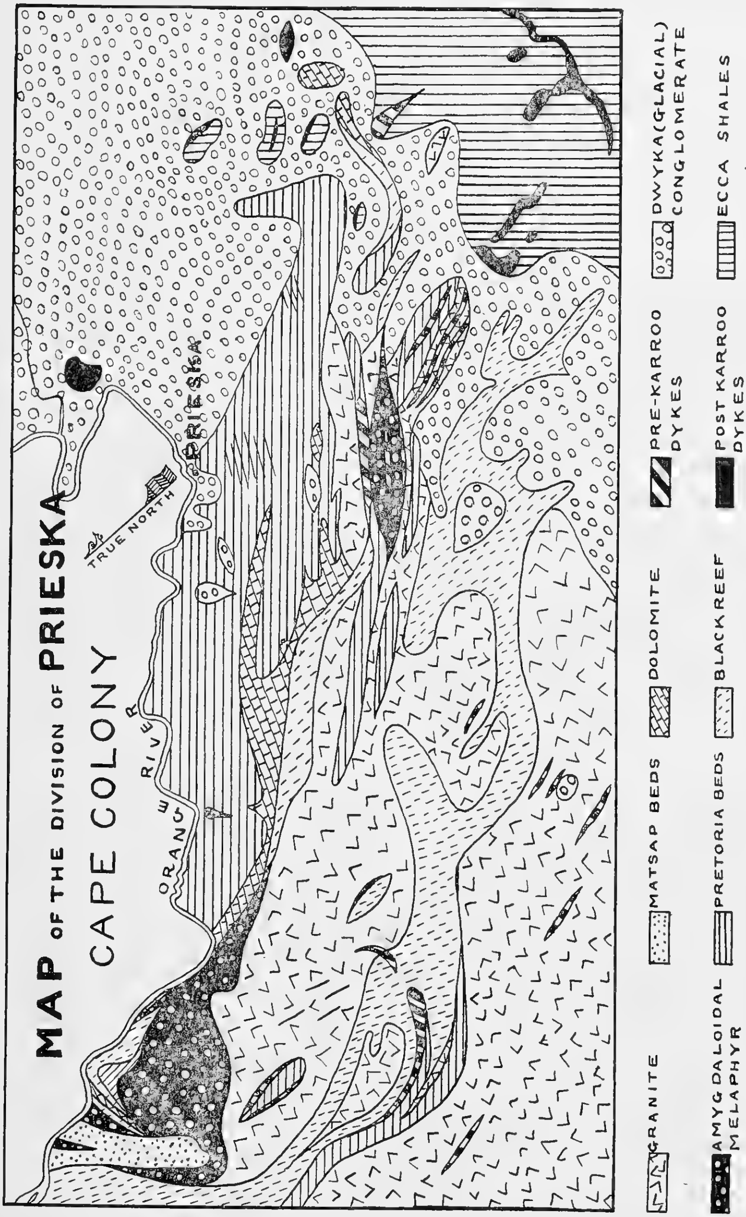
From time to time the accumulation of new facts in any one science renders it necessary to examine into the cause for the existence of certain features, and to see whether some small points which rendered the earlier explanations not altogether satisfactory, may not be entirely accounted for in the light of the new experience. In many cases this proceeding has resulted in the entire recasting of our ideas concerning certain phenomena, especially in the physical sciences where laboratory demonstration can prove the truth of the new law; in geology, the unwieldy nature of the subject-matter, and the different aspects which the same country or mountain may present to different obseıvers, renders this method somewhat unsatisfactory. It must, however, be done, if the science is to progress, although in the end a categorical statement that the new explanation is a true one, and the old one a false one, cannot be made. It is the purpose of this paper to pick out certain facts in connection with the amygdaloidal lavas of Prieska, Cape Colony, which cannot readily be explained on any of the theories of igneous extrusion, and to see whether they cannot be accounted for on some other theory; I shall summarise what is known of the fall of large meteorites and point out in what way the phenomena connected with these show certain significant resemblances to those exhibited by the amygdaloids of Prieska, tentatively suggesting that in the past huge bolides fell on the earth, melted the rocks in the neighborhood of the fall and produced these great fields of lava.

The meteorites that we examine in the collections of museums are small and would not by their fall make much impression on the earth: it is true that in the course of ages these small meteorites must add considerably to the bulk of the earth for it is estimated that some hundred thousands, if not some millions, of meteoric bodies fall upon the earth each day. Even these museum-specimen meteor-


MAP OF THE DIVISION OF PRIESKA
CAPE COLONY
TRUE NORTH
ORANGE RIVER
PRIESKA
GRANITE
AMYGDALOIDAL MELAPHYR
MATSAP BEDS
PRETORIA BEDS
DOLOMITE
BLACK REEF
PRE-KARROO DYKES
POST KARROO DYKES
DWYKA (GLACIAL) CONGLOMERATE
ECCA SHALES

ites, as I may call them, range up to sizes which would shake considerable areas of country by their fall, as for instance the Bacubirite meteorite, which is thirteen feet long and is estimated to weigh 50 tons.[1]

In the Coon Butte, Ariz., there is a crater which was described by Gilbert as volcanic, but subsequent investigation has failed to discover any volcanic material connected with it; on the other hand, strewn round it are masses of meteoric iron of which ten tons have been carried away at different times and now figure in collections as portions of the Canyon Diabolo meteorite. The rocks in the vicinity of Coon Mountain consist of horizontal beds of Aubrey limestone and sandstone belonging to the upper Carboniferous series. The mountain is formed by the up-turned edges of the strata making a jagged circular ridge varying in height from 120–30 feet above the plain. The chasm is 600 feet deep and 3,800 feet across. The nearest lava flows and cinder cones are twelve miles distant, while the San Francisco mountains which contain many volcanic cones are 45 miles away. The material at the bottom of the crater has been investigated by Messrs. Barringer and Tilgham by means of bore-holes down to 1,000 feet, and the rock encountered is mostly pure white silica which in some places is in the form of impalpable powder; scattered throughout this there are masses of varying sizes of pumiceous and more compact material, which chemical and microscopic examinations show to have been formed by the crushing and fusing of the quartz sandstone. Below the zone of crushed and fused material there is an underlying sandstone quite intact and unaltered.[2]

There seems to be no reasonable doubt that this crater is actually the result of the impact of a huge bolide and the absence of the large meteor itself is explained by supposing that the heat of the impact was sufficient to melt and perhaps vaporise its substance; certainly there is a large quantity of magnetic iron oxide lying as dust about the neighboring country, which, on analysis, gives a notable percentage of nickel.

[1] H. A. Ward, "The Bacubirite Meteorite," *Proc. Rochester Acad. Sci.*, 1902, IV, p. 67.

[2] D. M. Barringer, "Coon Mountain and Its Crater (Arizona)," *Philadelphia Acad. Nat. Sci. Proc.*, 1906, LVII, p. 861; B. C. Tilgham, *ibid.*, p. 887; G. P. Merrill, *Smithsonian Miscellaneous Collections* (quarterly issue), L, 1907, pp. 203, 461.

A large meteor need not necessarily be an iron one, and we have a remarkable block of melilite-basalt in Cape Colony which has certain features that point to its possible meteoric origin. The occurrence is at the top of the Spiegel River Valley in Riversdale; the outcrop of the rock is about 100 feet in an east-and-west direction, and half as much across, though, as it is found at the top of a hill, and the sides are strewn with débris from it, it is hard to determine the exact size of the block; there are bands of harder and softer material in it which give the mass the appearance of being bedded, and the dip is some 15° to the southeast. It is surrounded on all sides by coarse, loose conglomerates of Cretaceous age which show no disturbance whatever. Had the mass come up in a volcanic throat, one would have expected to see some evidence of the explosive force in the loose gravel, or some lateral dykes or fume vents, but nothing of the sort could be found, and no other volcanic rocks occur within many miles. The view adopted by the Geological Survey[1] is that it is a volcanic pipe filled in, but that is simply because no similar blocks have been described with which to compare it whereas melilite-basalt ordinarily occurs in connection with volcanoes.

If we turn to the moon whose surface being free from erosion and deposit should show clearly any marks made on it by the fall of meteorites, we find certain evidence which is highly suggestive. The craters which are scattered so freely over the moon's surface were thought by Gilbert[2] and others to be due to the impact of meteors; that they were not so formed we gather from the following considerations. In some of the craters the floor or top of the lava column stands many hundreds of feet below the general level of the surface, but in others the floor is as much above that level. The internal walls of the craters show definite terraces like old strand lines which have been formed by the successive retreat of molten material within the volcanic chimney. The craters, especially the smaller ones, often lie upon definite lines of fissures like the volcanic fissures of Iceland, an arrangement which would have been impossible had they been formed by the infalling of meteors. Lastly there is a regular

[1] A. W. Rogers and E. H. L. Schwarz, *Ann. Rept. Geol. Comm.*, 1898, Cape Town, 1900, p. 62.

[2] G. K. Gilbert, *Bull. Phil. Soc. Washington*, XII, p. 241.

scale of dimensions corresponding with antiquity in the craters, the larger being the older and the smaller ones successively younger; this we can establish both from the fact that the smaller ones often breach the larger ones, as well as from the freshness of the rocks about the smaller ones as compared with those surrounding the larger ones; for although there is no atmospheric weathering in the moon, the alternate heating and cooling of the surface brings about a certain amount of alteration which in time produces sufficient effect to be clearly noticed through the great telescopes.

These craters do not belong to volcanoes such as exist on the earth but resemble rather the outbursts of entangled molten matter during the final consolidation of the moon, according to Professor T. C. Chamberlin's view,[1] and on such a theory the graduation in size is well accounted for. But after this stage was over, when the forces which brought the molten material from the interior to the surface had become spent, no matter what their actual nature was, then the surface of the moon was deluged with floods of lava, which, over tracts many hundreds and thousands of square miles in area, obliterated all pre-existing features and in their margins invaded and ruined the craters which stood in the path of the molten liquid. These *Maria* or dark patches of the moon occupy roughly one-third of the visible portion, and as seen through the great telescopes which bring the moon's surface to within 40 miles of the observer, their margins show that the material of which they are composed flowed in upon the rough ground as very liquid lava would do. It fills in the lower ground forming numerous bays, and in many instances, as is the case of the crater Doppelmeyer, it distinctly appears to have melted down the side of the crater-wall next to it and to have filled in the cavity to its own level. This feature is not confined to any one spot of any one *mare*, but is to be noticed throughout the several thousand miles of the extent of the margins, and leads one to the conclusion that the *maria* were formed by a once fluid matter of the sea inundating firm land. The quantity of igneous matter was very great, and in each *mare* or sea it seems to have appeared all at once, there being no mark of successive flows such as compose the extensive lava fields of the earth. The lava of the several *maria* never overlap, although the

[1] T. C. Chamberlin and R. D. Salisbury, *Geology*, II, p. 105.

gravitative attraction on the moon being only one-sixth what it is on earth, would allow very steep slopes at the front of even fluid lava flows. The origin of this lava is still hypothetical, but it is to be noticed that none of the volcanoes of the moon give forth freely flowing streams of lava, nor do any of the numerous fissures or faults on the lunar surface, some of which evidently penetrate deeply, distinctly give rise to lava flows; generally it is established that all the volcano-like openings appear always to have retained their lavas within or near their walls, or, in other words, there was no tendency for lava to pass up to the surface in large quantities.

There is no evidence in any of the *maria* that the lava came up from a central pipe or from an elongate fissure; the general form of the seas is rounded or oval, and it would seem to indicate that if the fluid came from within, the lava should have emerged as from a terrestial volcano pipe, for if it came from fissures these should have been of elongate shape. But if the lava came either from fissured or from pipe-like openings there should be a grade to the flow extending from the center of the field to its margin; owing to the slight value of gravitation this grade should be steep. There, however, is no trace of such a slope; on the contrary, the curve of the margin of illumination shows the surfaces of the *maria* are essentially horizontal.

The hypothesis which fulfils most of the conditions of the case with respect to the origin of the lava of these *maria* in the moon is that great meteors fell upon the moon and by their impact produced sufficient heat not only to melt up their own substance but a good deal of that comprising the adjacent lunar surface. Even beyond the seat of impact, the shearing strains would probably be sufficient to convert much of the material of the surface into a fluid state, with the result that a mass of lava of a very high temperature, equal at least to the bulk of the invading body and probably several times as great, would be sent radially from the point where the impact took place. The evidence of melting effected by the material which forms the plains of the *maria* is considerable at several points, notably in the case of the craters on the margins of the seas. It seems quite certain that the walls of these craters next the sea have been in some manner effaced by contact with the material which came against it; in the case of the crater Flamstead in the Oceanus Procellarum, the

crater-wall has been almost melted down, but still rises slightly above the surface of the inundation; good examples are also seen in the Mare Tranquilitatis, Fig. 1. At many points the material forming the *mare* comes against extended steep-faced cliffs, which have the same general character as the inner slopes of the great craters, where the form of the declivity certainly has been determined by the melting action of the lava of the base. Further, where there are depressions in the area in the borders of the *maria*, the material of which they are composed flows into them as a fluid would have done.

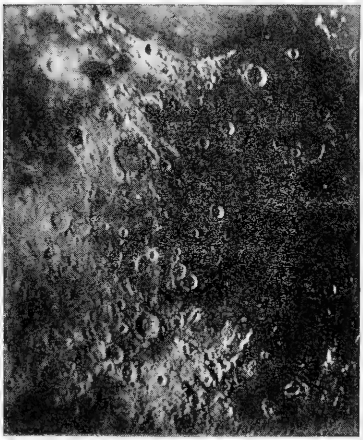


Fig. 1

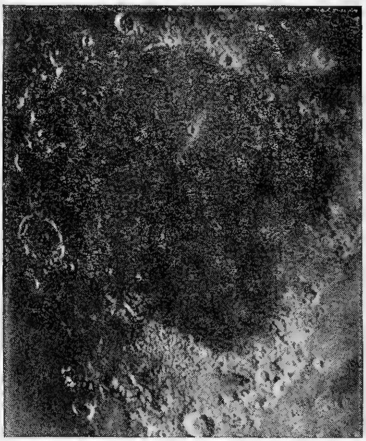


Fig. 2

Photographs of the Moon's Surface, after N. S. Shaler

Fig. 1.—Mare Tranquilitatis with Mare Serenitatis in the upper portion of the plate, showing the margin invaded by lava floods.

Fig. 2.—Mare Serenitatis, showing on the left the large crater Posidonius and above it the crater le Monnier which has part of its wall broken down by the lava of the *mare*.

The great objection to the hypothesis that the *maria* were formed by molten rock produced by the impact of large bodies falling upon the surface of the moon is that similar bodies competent to generate a great deal of heat have not fallen upon the earth's surface in the time which has elapsed since the beginning of the geological periods; there is so far indeed no recorded geological reason for supposing that they have ever fallen upon the planet, but it is just such evidence that I wish to submit. It must, however, be remembered that the moon's

surface took its shape long before the beginning of our geological record, so that if such evidence is to be found on the earth, such lavas of extra-terrestrial origin must be among Archaean rocks, where the unraveling of the tale would be extremely difficult, or they would be hidden under superincumbent strata. It is to be noted also that even in this stage of the evolution of our solar system there remain bodies in order of size such as would in falling upon the surface of the larger spheres produce the effect which we observe in the *maria;* thus the group of asteroids between Mars and Jupiter, though generally of far greater mass than would be required by impact to melt the larger of the *mare* fields, probably contains many bodies which in case of collision with our satellite would bring about the consequences which can be noted. At least one such mass of matter, Eros, has recently been discovered at no great distance from the earth.[1] It is probable that in a former state of the solar system when the moon was assuming its present surface features, these detached masses of matter were more abundant than they are at present. The tendency would be for those near the great spheres to be drawn in upon them, with the result that they would become rarer near the planets and the larger satellites.

Having then established the fact that giant meteors may have fallen on the earth and may have melted up tracts of country which would be deluged with lava without apparent vent or orifice from the interior, we can legitimately inquire whether there are any evidences of such occurrences on the earth's surface? There are many vast tracts of lava known on the Earth which offer tempting fields for speculation in this connection, such as the great lava sheets of the Snake River in Idaho, the Deccan traps of India and the Kapte Plains of British East Africa, and even the occurrence on these of small cinder cones and beds of ash and tuff does not necessarily prove that the material came from the interior of the earth, any more than the small blister cones on a flow of molten iron prove that the subjacent floor is riddled with blowholes, but I wish in this introductory statement to confine my remarks to one field which I know thoroughly.

In the district of Prieska, south of the Orange River, there is a

[1] N. S. Shaler, "A Comparison of the Features of the Earth and the Moon," *Smithsonian Contributions to Knowledge*, XXXIV, No. 1438, Washington, 1903.

tract of country which has been cleared of its covering of glacial drift and stands today with many of the features which it presented in a remote geological period. The glacial drift is of Permian age, and the topography revealed with astonishing freshness, belongs to that or earlier epochs. The area was described by Dr. Rogers and myself in 1899[1] and consists of a base of granite on which rest the various formations of the Transvaal System, quartzites, dolomites, and banded jaspers, and the Matsap or Waterberg sandstone, unconformably above these. The rocks present a bewildering number of correlation difficulties and nearly all the low-lying ground is covered with the red Kalahari sand which obscures the junctions of the several systems of rocks. There are no rivers or stream beds with the exception of the Orange River, and all the water precipitated in the rare rains sinks through the sand and evaporates slowly leaving behind a crust of calcareous sinter. Weathering therefore is of the desert type, and the breaking down of the rocks is nearly entirely brought about by expansion and contraction, without chemical change of the constituent minerals. For this reason the less compact Permian and Triassic clays and shales of the Dwyka and Ecca Series have yielded easily to the forces of destruction and have been blown away; the underlying rocks, however, of dense crystalline structure or of compact metamorphic nature, have emerged with relatively slight alteration from their burial beneath the Karroo rocks. The younger rocks were invaded by dolerite intrusions belonging to the great system of dykes and sills that extends right across South Africa almost from sea to sea, but the older are penetrated by a number of dykes of the most varying types which have been altered by crushing and metamorphic action generally so that they can be described as diabases, granulites, hornblende-schists, and serpentine with chrysotile. Besides these last there is a third class of intrusive rocks which is, paradoxically, amygdaloidal.

These amygdaloidal melaphyres are known throughout the region of the Palafric rocks, whether we trace them on the surface in the Colony, Bechuanaland, or the Transvaal, or encounter them

[1] *Ann. Rept. Geol. Comm.*, Cape Town, 1900; see also E. H. L. Schwarz, *Trans. Geol. Soc. S. A.*, Johannesburg, 1905, VII, and A. W. Rogers and E. H. L. Schwarz, "The Orange River Ground-Moraine," *Trans. Phil. Soc. S. A.*, Cape Town, 1900, IX.

in the depths in the mines of Kimberley. The main group of them occurs below the first member of the Transvaal Formation—the Black Reef Series—and was called by Molengraaff the Vaal River beds, but is now more generally known as the Ventersdorp beds. They consist of lavas of varying basicity ranging from melaphyres to felsites and rhyolites and are usually accompanied by enormous developments of agglomerate ranging from coarse boulder beds to fine volcanic ash.

Two areas of these amygdaloidal melaphyres occur in the Prieska district under discussion, while other and smaller areas are to be found in the neighborhood. The largest of the masses is found to the north of the district on the farm Zeekoe Baard; it wraps round the end of the range of hills called the Ezel Rand composed of Matsap (Waterberg) sandstone and separates these rocks from the granite to the west and partially interposes between them and the Keis or Black Reef quartzites. There is a small mass also lying apparently intruded in the Waterberg sandstone. On the south side of the Ezel Rand there are some steeply inclined beds of limestone and quartzite which look as if they were the basal beds of the great limestone series turned up by force from the direction of the center of the igneous mass. Toward the point of the Ezel Rand there are tracts of agglomerate which probably belong to the melaphyre. The southern extremity of the melaphyre is on the farm Geelbecks Dam where it tapers out; the greatest width of the mass is on the farm Blink Fontein where it is 9 miles across, and the extreme length is 30 miles. A large portion of the area mapped in as melaphyre is, however, covered densely with red sand, through which the rock only crops out occasionally; on Schalks Puts and on the eastern part of Blink Fontein there are conspicuous ranges of kopjes formed of the rock.

The melaphyre is in contact with the Keis (Black Reef) Series of the farms Ezel Klauw and Louis Draai on the north, and with the Matsap (Waterberg) beds of the Ezel Rand, which it surrounds on three sides. To the south it is bounded by the Campbell Rand (Dolomite) Series on the one side and the granite on the other. The field-relationships are not compatible with the supposition that the origin of the melaphyre was volcanic, unless a group of faults is brought in to explain the contact of the amygdaloid with such a large

range of rocks of widely separated ages; there is no evidence of such faulting, and although the rock is a typical lava, fine-grained to glassy in structure, and generally full of steam cavities, Dr. Rogers and myself were forced to the conclusion that the rock was an intrusive one and came into position after the earth movements affecting the Matsap beds had taken place.

About 30 miles in a southeasterly direction, reckoning from the southern extremity of the Zeekoe Baard mass, there is a second outcrop of amygdaloidal melaphyre on the eastern portion of the farm Jackals Water, and on the western part of the farm Prieska's Poort. The outcrop is elongated about 6 miles long and $1\frac{1}{2}$ miles wide, trending northwest, the direction of strike of most of the Palafric rocks in the Prieska district. On the northeastern side the melaphyre is bounded by the granite of Prieska's Poort, and on the southeastern side by the Keis quartzites on the farms Jackals Water and Uitzigt.

Similar rocks in the neighboring districts which appear most certainly to be intrusive have strengthened the view that the Zeekoe Baard and Prieska's Poort amydaloids are instrusive, but against this we have the steam-holes and agglomerates—clear indications of volcanic origin.

If we accept the volcanic origin, then we must imagine that from a central vent or fissure some extremely fluid lava was poured out, which flooded all the low-lying country, wrapped round the hills, and finally cooled as a plain of lava. No known volcano fulfils these conditions, and from what we know of lava we would be inclined to state that such a mass could not be suddenly ejected at any one time, but would rather come up in separate flows, each of which would travel outward and downward and would cool long before it could wrap round the end of a range of hills such as the Ezel Rand, in the manner of a perfectly liquid substance. Then again we find the agglomerates at the periphery of the Zeekoe Baard mass, and here, also, to the north, there is evidence of thrust.

In whatever light we look upon these Prieska outcrops of amygdaloidal lava, confining our ideas to a terrestrial origin of the material, we come upon insuperable difficulties, but directly we admit the possibility of the fall of a meteor sufficiently large to melt up a portion of the earth's crust, all these difficulties vanish. The sudden develop-

ment of a large quantity of liquid lava, the permeation throughout of steam holes from water contained in the rocks melted, the ridging up of portions of the periphery of the mass, the absence of true volcanic ash, but the great development of crushed up material entangled in molten rock—all these phenomena receive an adequate explanation on the meteor hypothesis. That the masses of lava often tail out into apparent dykes can be readily accounted for from the fact that earth movements have gone on since the development of the lava and such dyke-like extensions would be portions drawn out by crushing just as a crystal of felspar is drawn out in many gneisses.

Against the general acceptance of such a theory there is the objection that certain of the Archaean and early periods are characterized by just such volcanic rocks as are to be found in Prieska, great masses of lavas and clastic igneous rocks of all sorts. If any of such volcanic areas owe their rocks to meteors, it is certainly probable that the masses of planetary matter were grouped in swarms which would produce the same effect on the whole as a general outburst of great volcanoes over the earth. Each swarm would gradually discharge the individual bolides as the earth in its course round the sun came within attracting distance, and when the swarm was exhausted or passed out of reach of the earth's attraction, then there would be a secession of the production of these igneous rocks and normal sedimentation would take place.

In conclusion I must repeat that I do not contend that I have proved the meteoric origin of the amygdaloidal melaphyres of Prieska; but I maintain that the facts that we now know force us to take into consideration, when dealing with these extensive tracts of molten material on the surface of the earth, their possible origin from the collision of large meteorites. Everywhere we look in the older rock systems, we find enormous deluges of igneous material which are difficult to explain on the theory that the mass came from the interior of the earth, such as, for instance, the Bushveld igneous complex in the Transvaal; the object of this paper is to point out a possible cause in many cases, which so far has not been recognized.

EROSION AND DEPOSITION IN THE SOUTHERN ARIZONA BOLSON REGION

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Outline of Paper

Introduction

Physiographic Division of Arizona into Plateau and Bolson Country

Discussion of the Term "Bolson"

Topographical Features of the Bolson
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- Bajada
- Playa

Analysis of Geological Agencies under the Stimulus of Aridity
- Torrential precipitation
    - Theoretical analysis
    - Description of bajada building
    - Factors affecting slope of bajada
- Wind action
    - Method of attack
    - The development of resistant pavements
- Underground water
    - Water level
    - Moisture table
    - Crust deposits

Climate. Discussion of the factors quantitatively important, and classification of the following types
- Type 1. Torrential precipitation dominant
    - Torrential concentration (extreme or moderate) in either case with daily temperature difference (extreme or large)
- Type 2. Protective plant covering controls
    - A moderate and distributed rainfall, with no great extreme of daily thermal range
- Type 3. Wind action important
    - A thin distributed rainfall grading to no rainfall, and daily temperature difference (extreme or large)

Deposits of the Bolson
- The bajada outwash. (*a*) Inclination. (*b*) Upper limit. (*c*) Size of material. (*d*) Shape of boulders. (*e*) Decomposition of material. (*f*) Sorting. (*g*) Arroyo trains. (*h*) Sand pockets. (*i*) Change in layers. (*j*) Stratification.
- Playa deposits. (1) Lake. (2) Standing water mud sheet. (3) Outwash mud sheet. Modifications induced by evaporation and wind erosion.
    - Structure of the lake deposits. (*a*) Strands and terraces. (*b*) Distribution of coarse and fine. (*c*) Composition and lack of subaerial markings.

Structure of the playa muds. (*a*) Chemical deposits. (*b*) Surface markings. (*c*) Animal and plant remains. Erosion of the mud sheet.

Climate as Affecting the Erosion of the Bajada

Discussion of (1) the remains of an older bajada near Tucson, Arizona, and (2) the incision of the younger bajada by the larger gullies; showing that while climate theoretically might be competent, the facts of the case suggest that other conditions were the immediate cause of this erosion, and finally that climatic changes are better read in the detail of structure and composition of the deposits, rather than in topography.

INTRODUCTION

Before the publication of Barrell's studies on climate and deposition,[1] I wrote:

> It does not seem probable, therefore, that theoretical analysis of the complex relations that obtain between climate and deposition will accomplish what it has in the case of deposition by running water and by glacial action. The problem will be solved by detailed studies in each region. In each case the disturbing factors must be evaluated, and the intensity of each process gauged.[2]

The study of Barrell's article did not seriously affect the above opinion, but it did suggest and encourage the following contribution, on account of the evident value of his analysis in directing attention to the newly developing study of climatic effect on geological processes, in showing its possibilities, and in suggesting some of the criteria available.

In this contribution attention will be confined to a certain definite portion of the arid southwest, which is here called the bolson region. A criticism by Keyes of Hill's definition of the term "bolson"[3] and its use by Tight, Lee, and others gives point to an investigation of the history of the use of the word, and a discussion of its proper meaning.

The data to which this treatment owes its development have been collected during a residence in the arid southwest since 1901. The

[1] Joseph Barrell, "The Relation between Climate and Terrestrial Deposition," *Jour. Geol.*, 1908, pp. 159–90, 255–95, 363–84.

[2] C. F. Tolman, "The Geology of the Vicinity of Tumamoc Hills," *Publication 113*, The Carnegie Institution of Washington (in press).

[3] Hill, *Topographic Atlas of the United States*, U. S. G. S.; Keyes, "Bolson Plains and the Condition of Their Existence," *Am. Geol.*, Vol. XXXIV, pp. 160–64; "Bolson Plains," *Am. Jour. Sci.*, Vol. XV, pp. 207 ff.; "Rock Floor of the Intermont Plains of the Arid Region," *Bull. Geol. Soc. Am.*, Vol. XIX, pp. 63–92; Tight, "Bolson Plains of the Southwest," *Am. Geol.*, Vol. XXXVI, pp. 271–84.

earlier portion of this time was spent in constant traveling over southern Arizona, and northwestern Mexico. In order that the value of the observations and deductions presented may be approximated, it is frankly admitted that until recently attention was not directed to the broader features of desert physiography. The attitude of mind, bent on the study of the details of ore deposition, and therefore investigating minor features so important in that study, was carried over to the examination of the sedimentary deposits, and details of texture and structure, and their possible explanations were readily noticed. It is believed that such a study, undertaken systematically, however, will reveal the intimate relation between climate and deposition.

PHYSIOGRAPHIC DIVISIONS OF ARIZONA

Arizona has been divided into the plateau region, the range region, and the volcanic region by Gilbert, and later by Ransome into the plateau region, the mountain region, and the desert region.[1] A twofold division is preferred for the purposes of this paper, the separating line being the great Mogollon escarpment and its extensions, as shown on Robinson's map of the Colorado Plateaus.[2] The northern portion is designated as "the mesa or plateau region," and the broken area to the south the "bolson" country. The plateau region will not be under consideration, the student being referred to the unsurpassed descriptions of Dutton, and the recent work of Robinson and Lee.[3]

The generalization that this southern region is an intricately broken-down portion of the central plateau is remarkably true considering the broadness of the statement, the regularity of the broken fault-blocks, however, is modified by the complicated post-Carboniferous intrusive masses. Further the form of the secondary hills is

[1] Gilbert, "Report on the Geology of New Mexico and Arizona," *U. S. Geol. and Geog. Survey of the 100th Mer.*, Vol. III; Ransome, "The Geology of the Globe Copper District," *Prof. Paper 12*, U. S. G. S., pp. 14–16, with map.

[2] Robinson, "Tertiary Peneplains of the Plateau District," *Am. Jour. Sci.*, August, 1907, p. 123.

[3] Dutton, "Tertiary History of the Grand Canyon Region," *Mon. II*, U. S. G. S.; Robinson, *op. cit.*, pp. 109–29; Lee, "Geology of the Lower Colorado River," *Bull. Geol. Soc. Am.*, Vol. 17, pp. 275–85.

often controlled by a mosaic of small fault-blocks, showing a remarkably close relation of hills and gullies to blocks and faults. Toward the south and southwest, the fault-blocks develop into parallel strips; ridge after ridge of Paleozoic limestones, and successive sheets of rhyolitic and andesitic lavas rear their heads above the desert-filled wastes. These fault-strips, rather than fault-blocks, are well developed southwest from Casa Grande, the steep scarps facing northeast, and the faults striking northwest, the most important escarpment being that of the Vekol Mountains where several thousand feet of Carboniferous strata are exposed, with an unusual development of upper arenaceous members. The waste between the hills consists of wash deposits, volcanic deposits, playa deposits, and occasional lake deposits, this complicated series dating back through the Quaternary and probably the late Tertiary. Sufficient data have been collected by scattered observations to indicate that in their structure they show the effect of various conditions of climate and topography, and give color to the belief that the history of the Quaternary at least will be discovered by a well-directed reconnaissance of the region.

DISCUSSION OF THE TERM "BOLSON"

With the above description in mind, it is evident that southern Arizona is a region of bolsons, as defined by Hill. He states:

> The bolson plains . . . . are newer and later features consisting of structural valleys between mountains or plateau plains, which have been partially filled with débris derived from the adjacent eminences. [1]

Keyes strenuously objects to the application of the term so defined to the New Mexican examples. He states that the Jornado del Muerto, and Estancia plains are valleys showing erosion bevelment, and are not structural, and that they have but a thin veneer of desert waste.[2] Going farther, he states that New Mexican plains are in general destructional planes, in soft Cretaceous strata with only a thin capping of desert waste, and by assumption these conditions are extended to cover Arizona bolsons. Tight has taken exception to these conclusions as applied to New Mexico, and certainly in the structurally broken country of southern Arizona, the deeply filled,

[1] *Op. cit.*, p. 8. [2] *Op. cit.*, pp. 66, 67.

undrained, or feebly drained areas, corresponding to Hill's definition, exist par excellence. Here there is little danger of confusing soft Cretaceous strata with the later fill.

The following list showing the depths of a few typical wells in the southern bolson region is compiled from a large number of logs furnished me through the courtesy of the Southern Pacific engineers and others. As the wells are sunk only to a good flow of water, the depth of the fill is not known in any case. The Esmond[1] well is especially interesting, as it is situated toward the eastern edge of the semi-bolson of the Tucson District, about five miles from the nearest rock slope, and yet it shows 1,480 feet of typical outwash material. These wells indicate surely more than a "thin veneer" of detrital outwash.

Well	Depth, Feet	Character
Safford S. P. well.........	1,820	Bolson lake beds
Benson S. P. well No. 2...	717	Chiefly bolson lake beds
Benson S. P. well No. 3...	806	Chiefly bolson lake beds
St. David's Artesian well....	530	Chiefly bolson lake beds
Esmond S. P. well	1,480	Tucson semi-bolson deposits
Gila S. P. well............	1,386	Semi-bolson. Lava flow from 1,250 to 1,290
Casa Grande S. P. wells...	615 625	A semi-bolson in Santa Cruz drainage in a region of typical bolsons
Sentinel S. P. well, No. 1..	1,129	Showing 1 lava flow in section
Sentinel S. P. well, No. 2..	962	Showing 2 lava flows in section
Sentinel S. P. well, No. 3..	1,082	Showing 2 lava flows in section and all three are typical wash deposits of a semi-bolson region
Wellton S. P. well.........	1,120	A semi-bolson near Colorado River

The word "bolson" of course is of Spanish origin, and its application by the early Spanish settlers and their descendants shows a keen eye for topographic forms, painfully lacking in the later American invader, who with perfect unconcern will, for instance, designate the surface of a topographic basin as a mesa (a table).

In looking over a collection of old maps of the southwest at the Carnegie Desert Laboratory, I find that "Bolson Mapimi" appears on Thompson's *New General Atlas No. 50*, published in 1814, and since then the word has been in continuous use as a technical geographical term. Hill's definition is faulty in that it imposes a restriction which is only possible of application after the geological structure

9 *Publication 99*, The Carnegie Institution of Washington, pp. 58, 59.

of the region has been worked out, and not justified, considering the great priority of the Spanish usage.

The geologist is not the only one that has a right to be heard in this matter, for the problems of the desert are being attacked enthusiastically and successfully by the botanist, and it is only by the combined action of the two that the broad problems of desert history and climate will be solved. There is a need for a word by which the individual self-centered drainage systems of the desert can be designated, and we should return to the original and broader meaning of the word bolson. I therefore suggest that the word be used to cover the watershed of a centripetal drainage system, including all the area within the limits of the divides.

The bolson may depart somewhat from a perfect topographical basin, for evaporation on a slope may prevent the development of a through drainage, and foster the centripetal variety. Those bolsons whose surface water *in times of flood* reaches some river thoroughfare, some lower bolson, or the ocean direct, and consequently the playa portion described below is poorly developed or lacking, may be called semi-bolsons. In Arizona, therefore, there is every gradation between bolson, semi-bolson, and ordinary river drainage, the latter becoming more prominent as the Colorado River is approached.

TOPOGRAPHY OF THE BOLSON

The well-developed bolson presents three distinct topographic features. (1) *The Upper Rock Surface.*[1] The slope of this surface is a function of rock structure and composition, and erosive attack. The top surface may be a mesa, developed either on account of protective action of some hard layer, or an older erosional flat, which on the top of the higher mountains is protected on account of the forest growth.[2] The latter are so discontinuous that they have as yet defied any general correlation, and the discovery thereby of a faulted peneplain. (2) *The bajada.* Extending down from the rock surfaces are the flanking detrital slopes,[3] built up by terrestrial

[1] Tolman, *loc. cit.*, gives photographs and diagram illustrating bolson topography.

[2] Example, top of Catalina Mts., north of Tucson, Arizona.

[3] Blake, "The Flanking Detrital Slopes of the Mountains of the Southwest Portion of the United States," *Science*, new series, Vol. XXV, p. 974, states conclusions at variance with those presented here. Probably the best descriptions of all the different features of bolsons are found in Carnegie *Publication 26*, "Explorations in Turkestan."

deposition, the aggradational equivalent of the active erosion above. These slopes are the dominant feature of the arid landscape, each mountain range (or isolated hill under severe climatic conditions) appearing to stand on a symmetrical pedestal. The novelty of these features, and the prominent and distinct place they hold topographically, have led to a repeated request for a formal name. In a former publication already referred to, I recommended the use of the term "slope," describing each particular incline by the name of the mountain which gave it birth: viz., Tumamoc slope, Catalina slope, etc. The difficulty of preventing confusion between the detrital slopes and the rock slopes of the mountains brought out the necessity of a new name for this feature, for which the Spanish word *bajada* has been selected, local usage almost exactly corresponding to the technical meaning suggested. (3) *The playa.* Finally in the well-developed bolsons, there is a central flat, or flats in the irregular and larger bolsons, which is occasionally or even permanently occupied by a water sheet, the life of the temporary lake or pond depending on local climate conditions. In less perfect examples of the semi-bolson this central feature is lacking. In such a bolson, especially where large, the central portion may be a more or less irregular plain, composed of river, outwash, and other deposits, and the general name to be applied is "bolson plains."

ANALYSIS OF GEOLOGICAL PROCESSES IN ARID REGIONS

Torrential precipitation.—Before attention is directed to the aggradational deposits of the bajadas and playas, a preliminary investigation is advisable regarding the action of geological processes under the stimulus of aridity. It is generally assumed that all the precipitation of the desert regions is of torrential character. This is the exaggerated recognition of the fact that there is a marked tendency in that direction, and even where a given shower has no greater density than one in humid region, the run off is more rapid, and torrential concentration accentuated.

Assume a moderately arid region, with a marked tendency toward torrential concentration of precipitation, with both a large daily thermal swing (marked difference between day and night temperatures) and an active wind transportation and deposition. The coarse

material is pried off and made ready for the attack of torrential stream by daily temperature change, and the fine material is brought up by the wind. There is no grading in size between the two, the deficiency of material of intermediate size being marked.

Under the well-known erosion analysis in the case of "a homogeneous island with one depression" let any flood encounter a depression of any kind accelerating its flow, then there *must* be a gullying started which will work up stream. Now the sheet flood described below often flows over irregular ground, and even then its gullying action is almost entirely lacking. The observation of this phenomenon led to an investigation of the manner in which material is transported by flood action. It has not yet been possible to check observation with experimental data, but on account of the bearing on the problems at hand, I present the following inspection of certain phases of this transportation.

Sediments are carried forward by running water in the following three ways: (1) The large material is rolled on the bottom; (2) Finer material is thrown up and down by subcurrents, drifting forward with the current; (3) The superfine is held in suspension by the kinetic action of inter-impact.

1. As is well known the mass of the largest particle that can be rolled on the bottom varies approximately as the sixth power of the velocity of the stream at its bottom. The material rolled comprises the cutting machinery of the stream, and the fact that the size increases so rapidly with quickening velocity, gives to the stream its great power of concentration of energy at declivities and at the down-stream side of hard strata. If a stream is in the rather unusual position of having no coarse material to roll on its bottom, it will not only not be able to cut hard rock, but it will have nothing with which to stir up the finer material in its channel, and therefore its cutting power is reduced.

2. The intermediate and fine material is danced upward by the secondary currents, eddies, etc., of the stream, and during its up-and-down journeys it is carried forward by the current. The formation of these eddies is generally recognized[1] and they are shown in an impressive way in the eddies and whirlpools of the sullen mud-laden floods of the southwest. The whirls are formed by friction both

[1] See Chamberlin and Salisbury, *Geol.*, Vol. I, pp. 111, 112.

along the bed of the stream, and between the layers, as shown in Fig. 1. The bottom whirl can probably be considered of primary importance, because (*a*) at the bottom there is the greatest friction, and therefore, the greatest difference of velocity; (*b*) the bottom whirl has an unbalanced upward velocity: (*c*) the higher whirls have equal upward and downward components, and can affect only the material they have received from the bottom whirls. They will accelerate the upward motion of some particles and retard others to the same extent. Therefore in this preliminary inspection the action of the bottom whirls only is considered. Although the motions will be complex, assume a certain whirl which represents the average upward throw of the stream. Increase the velocity of the stream and the subcurrents will increase presumably approximately directly as the velocity of the stream.

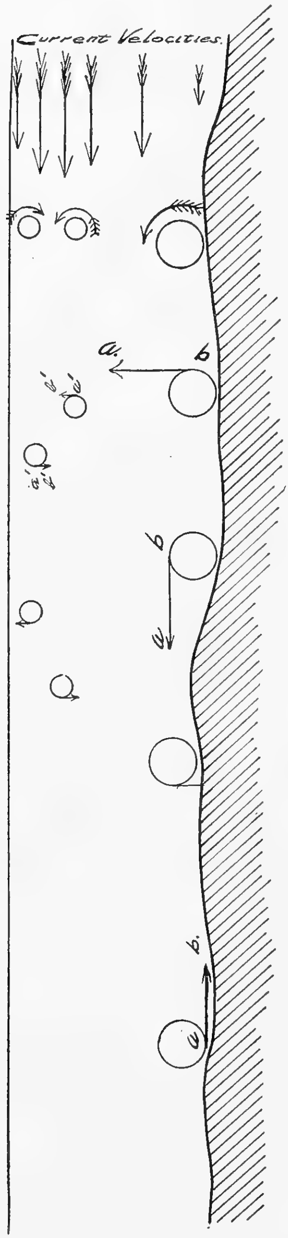

FIG. 1.—The current velocities are indicated at the right. The throw of the bottom whirls is indicated by the arrows *a*, *b*. The small intercurrent whirls have balanced action and receive material from the bottom whirls, and are not important.

Following the course of events as they commonly occur in arid regions, let us assume that the sudden shower or cloudburst picks up a great load of both coarse and fine. Let this shower be on the rock slope of a bolson. There is no dropping of coarse and picking-up of fine material as is postulated for the ordinary stream, because mountain-slope and torrential concentration give a great excess of energy, so

that everything loose on the surface is swept down into the steep canyon. The grade of the canyon decreases below, and deposition commences, boulders first and the rest following in decreasing size according to the v^6 formula for mass to velocity. Here the ordinary backing-up effect is not important. Permanent streams generally develop deposition at a certain point, and this works back, the current damming itself up. The torrent, however, drops its coarse at the top and the rest continuously on its downward path, resembling a single wave rather than a continuous current, so that the effects of deposition are not readily transmitted backward. Wash deposits often show simultaneous dropping of coarse and fine together, as a result of rapid checking of velocity, the formation consisting of a conglomerate of pebbles or boulders set in a matrix of sand or mud, the boulders carried down by the deepest rush of the torrent, and filled in with sand by the subsiding water. Such a deposit indicates clearly the agency of torrential flood. Farther down there may be a spreading-out of the flood as a widening sheet of mud and water. This is the flood sheet, and it may be either the expanded lower portion of the torrent from far above, or the even sheet of run-off from a shower on the lower detrital slope. The coarse material has been dropped, and the fine is now carried wholly in suspension.

The ordinary conception of a loaded stream is one that is picking up material to its full capacity, and also one that has the fine material at hand so that the picking-up and the laying-down are in equilibrium. To increase the capacity of a stream to carry material in suspension therefore, it is necessary to increase either (*a*) the number of bottom subwhirls, or (*b*) the number of particles cast upward in unit time by each subwhirl, or (*c*) the average upward throw of the bottom whirls.

Let these factors be represented respectively by m, n, and d, and L the carrying capacity of a stream for fine material suspended by subcurrents.

$$L \propto mnd. \tag{1}$$

We have assumed certain whirls distributed over the bottom, representing the average upward throw of the stream, and that fine

material of a single size is being transported; therefore m can be considered a constant. Both n, the number of particles thrown upward, and d, the distance of throw, depend upon the velocity of subwhirl, which was assumed above (on account of lack of experimental data) to vary approximately directly as the average current velocity,[1] or

(2) $$L \propto v^2.$$

Assume that in the tumultuous advance of the flood sheet, the average throw of the subwhirls is equal to the depth of the stream (Fig. 2, A), then an increase in the velocity (due to some irregularity in its path) cannot increase d (Fig. 2, B), because the particles cannot

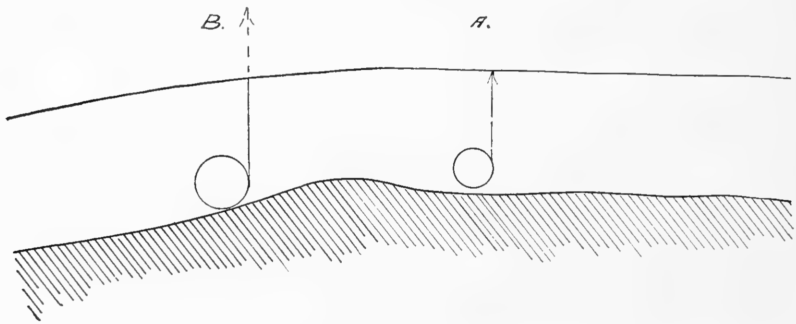

Fig. 2.—A. The average upward throw of the bottom whirl is equal to the depth of the stream. B. The average upward velocity imparted by subwhirl is greater than that necessary to take the particle to the surface.

be thrown above the surface of the water. Therefore under these conditions

(3) $$L \propto v.$$

This shows only a very moderate increase in carrying capacity, not at all comparable with the effect of current velocity on the power to *roll* material forward, which seems generally to have been assumed to govern the eroding power of a loaded stream on receiving an increase in velocity.

In the above analysis, it was assumed that the material shot up by the whirls sinks downward undisturbed by other currents. As a

[1] The Colorado River offers excellent opportunity to study the difference in velocity at various depths in times of flood when silt laden, and in times of clear low water.

matter of fact the whirl must produce upward and return currents. Therefore the effect of increased subwhirl velocity in shooting up a larger number of particles will be in part balanced by a more rapid downward journey of the same particles due to the increased velocity of the complementary return currents. Therefore

(4) $L \propto$ less than directly with v.

Will, however, this moderate increase in power to suspend material be effective under the conditions that obtain in the arid southwest? Is there loose material to pick up? Is equilibrium easily established between the material in the stream and the material on the ground over which it passes? The flood is advancing over a surface that (1) may be a baked mud flow, or (2) is cemented by desert salts, or (3) is protected by pavements described later; therefore it cannot cut, for its tools have been laid down above, and it cannot pick up loose material, for that has been swept away by the wind.

3. It has been suggested to me by Dr. A. E. Douglass, of the University of Arizona, that the finest of the material is not suspended by the subcurrents, but that due to the difference in velocity in the various layers of the water, the numerous superfine particles are in constant collision, and the kinetic bombardment (like that of solutions ascribed to heat) causes a diffusion of particles upward from the region of greatest velocity difference, viz., the bottom. Further, it is to be suspected that the attached air bubbles aid in the suspension of the emulsion, for after boiling a mixture of very fine loess, Dr. Douglass found that the cloud of particles did not rise as readily upon rotating the containing vessel as before. The increasing power to suspend superfine material from the increase in declivity will not cause noticeable erosion, however, on account of a lack of loose fine material of this nature.

We may conclude therefore that a flood sheet is far less responsive to moderate increase of gradient, than an ordinary stream. It is a depositing and not an eroding agency and will not develop into the former even when subject to a moderate increase in current velocity.

As the flood sheet advances its velocity is checked (1) by evaporation, to a minor extent, (2) by absorption in the ground, and (3) mainly by spreading out to a thin sheet, thus greatly increasing surface

friction, the final layer of mud being left at or toward the bottom of the slope.

I have described the ideal case in which the descending water spreads out into the flood sheet. This particular phase, described by McGee, and emphasized by Keyes,[1] while not uncommon, has hardly the importance attached by those observers. It is in every case a depositing and not an eroding sheet, save when confined to a valley where it can do some undercutting, and it is strange that the term "sheet-flood erosion" should have been allowed to go unchallenged so long in geological literature. Final deposition on the margins of the bajada is more often by distributaries, as described by Johnson,[2] although again his statement that the latter is the only method is not in accord with the conclusions reached here.

In any case torrential action develops the three topographic surfaces mentioned above. The occasional storm will accomplish more work, in comparison to the precipitation involved, than more frequent cloudbursts, as the first can carry off the entire supply, leaving the following storms to rework its deposits. Provided that there is no marked change at the foot of the slope, such as earth movements affecting the same, damming-back of the bajada drainage by expanded water sheet, or a quickening of the temporary "through drainage," in the case of the semi-bolson, the initial angle of deposition depends upon a number of minor factors, a few of which are stated below in about the order of their relative value: (1) *Size of abundant fragments.* The relation of upper slope to the coarse material occurring in large amounts, is noticeable everywhere; (2) *Density of precipitation,* and (3) *Supply of detritus.* The largest bajadas should be developed with steepest initial slope where concentrated torrential precipitation is separated by intervals of sufficient time for the development of a large supply of detritus; (4) *Height of mountains above foot of bajada.* Attention will be again turned to the upper margin after climate has been analyzed.

Wind action.—The wind has been given the leading rôle among

[1] McGee, "Sheetflood Erosion," *Bull. Geol. Soc. Am.*, Vol. VII, pp. 87–112; Keyes, *op. cit.*, pp.78–82.

[2] Johnson, "The High Plains and Their Utilization," *Twenty-first Annual Report* U. S. G. S., pp. 612–22.

the physiographic agencies in regions of aridity, by some authorities, while others have given it an intermediate or even a minor importance. The fact is that wind plays a varying rôle from major to minor depending upon the variety of arid climate. This is investigated later and attention is now directed to the method of erosive wind attack and the resistant surfaces developed thereto.

It seems to be commonly believed that wind may attack successfully an unelevated or even a depressed flat surface.[1] It is true that the wind picks up most of the fine material it transports from flat lowlands, but this is largely a repicking of material dropped; of tourist-passenger particles on a stop-over ticket. The source is from certain limited areas that are undergoing erosion on account of special exposure and non-protection.

The larger portion of the surface of the southwestern arid region is fortified against the attack of the wind by desert pavements. Take as an example of extreme development those north of the Chocolate Mountains and west of the Colorado River, protecting an old flood-plain deposit of the latter stream. There the surface is covered with a perfect mosaic of fitted stones, polished and flattened to the last degree of perfection by the wind. The light of the early or late sun is thrown back from uncounted faceted mirrors, in a dancing blaze. Step on this pavement and you are surprised to find the apparently solid rock yielding underfoot. Scratch it with your boot, and you find that there is only a single thickness of pebbles, in size up to an inch in diameter, and at times less than a quarter of an inch thick, covering a deposit of hot, dry dust. A few trips of the wagon in the same tracks, will form deep ruts by the breaking of the pavement. The above description is of the most perfect pavement I have seen, but everywhere, except in the sorted sand of the dune regions, a strong wind develops resisting pavements. The wind attack upon a deposit of dry playa mud, mixed with occasional pebbles (such pebbles are common to all deposits on account of the vicissitudes of arid deposition) must proceed as follows: First (provided no crust deposits interfere), the wind can blow just as much dust as contains on the average a single layer of pebbles; second, this layer of pebbles

[1] Davis, "The Geographical Cycle in an Arid Climate," *Jour. Geol.*, 1905, pp. 385, 388, 391.

must be laboriously sandpapered to nothingness, before the second layer can be touched. MacDougal[1] reports that wheel tracks were seen on his trip into Lower California, that had been made sixteen years ago, and that the gun ruts of the Walker Filibustering Expedition are reported to be still visible in places after fifty years. In fact, a wheel track on such a pavement as is described above would last indefinitely according to ordinary popular measurements. The polishing of a horizontal surface is striking, but the erosion accomplished by this action can easily be exaggerated. The wind motion is nearly tangent to the ground, and the sand is danced lightly off a flat surface. Let a projecting face withstand the wind, however, and it immediately concentrates its energy to the work as vigorously as a youthful river to an opposing hard stratum. The maximum work is done where a crumbly horizontal sandstone attempts to withstand the wind. Here no talus protects the face of the cliff, and the opposing strata are completely chiseled off before the blast.[2]

The wind will undercut by working in the least resistant layer, the amount of this carving being limited by the talus from the harder layer above. Even the talus, however, is exposed to the windblast, and its removal may be assisted by torrential water, and yielding rapidly or slowly allows fresh attack on the cliffs.

A study of almost any erosion forms in an arid country shows undercut wind action, and further description is unnecessary. The action being most effective against vertical faces of horizontal strata, the wind terraces are driven back along the weak layers. There can be no question but that much of the amphitheater work of the Grand Canyon of the Colorado, and the level steps of the high plateaus of Arizona and Utah are developed by wind erosion.[3]

Underground water.—The depth at which underground water is encountered in bolsons is very variable. Considered in relation to surface geology, however, interest is not so much attached to the underground water table as to the surface moisture table. Recent

[1] MacDougal, "Botanical Features of North American Deserts," *Publication 99*, Carnegie Institution of Washington, p. 96.

[2] Whitman Cross, "Wind Erosion in the Plateau Country," *Bull. of the Geol. Soc.*, Vol. XIX, pp. 53–62, a striking example of the above.

[3] Keyes, *op. cit.*, pp. 81–83, 85–91, an extreme estimate of the importance of wind erosion.

experiments in dry farming show how a moisture table, elevated far above the water level, can be developed and protected by cultivation.[1] The crust deposits of the semiarid regions are believed to be developed by a similar moisture table. The rainwater penetrates with difficulty the dry soil, and while a portion may gain the larger openings and sink to the underground water level, a larger portion is caught in the capillary pores and drawn upward by the drying-out above, and laden with mineral salts deposits its load as the "caliche" crusts,[2] through evaporation at or near the surface. These crusts are built into the deposits, and are slowly recrystallized, forming the calcareous, gypsiferous, and even siliceous cement of the cement-gravels. The well sections examined in the vicinity of Tucson show that the amount of the cemented gravels may rise to 80 per cent. of the whole. Possibly the "mortar beds" of the high plains of Kansas, for which Johnson could find no adequate explanation[3] were surface crusts formed under local conditions of aridity, by means of an actively evaporating moisture table, and covered by subsequent deposits.

CLIMATE

I believe that in the future, when the recognition of climatic effects in sedimentation becomes general, the value of the recent articles by Barrell and Huntington[4] will be highly rated. Climate itself, however, needs still further analysis before its effects can be read satisfactorily in the strata. The critical factors from the erosional and depositional standpoint have not yet been determined, especially those that are in a measure the independent variables, nor has the

[1] See *Bulletins 103* and *130*, Bureau of Plant Industry; also Livingston, "The Soils of the Desert Laboratory Domain," *Publication 113*, Carnegie Institution of Washington; *Bulletin Agricultural College of Utah, No. 91;* Alway, "Studies of Soil Moisture in the Great Plains Regions," *Jour. Agricultural Science*, Vol. II, pp. 333–42.

[2] For description and discussion of the caliche see Blake, *Trans. Am. Inst. of Mining Engs.*, Vol. XXXI, pp. 220–26; Tolman, *loc. cit.;* Lee, *Water Supply Papers, No. 136*, U. S. G. S., p. 111.

[3] *Op. cit.*, pp. 643–57.

[4] Barrell, "The Relation between Climate and Deposition," cited above; "Relative Importance of Continental and Marine Sedimentation," *Jour. of Geol.*, Vol. XIV, 1906, pp. 316–56, 430–59, 524–68; Huntington, "Some Characteristics of the Glacial Period in Non-Glacial Regions," *Bull. Geol. Soc. Am.*, Vol. XVIII, pp. 351–85.

effect of the swing from one kind of climate to another received more than introductory treatment at the hands of Barrell.

Climate is the product of complex causes, a few of which may be considered the critical factors, and the rest quite subordinate. Barrell's classification of climate into warm and cold humid, and warm and cold arid, or again into constantly rainy, intermittently rainy, subarid, and arid, group together certain more or less decided expressions of climate, the fundamental factors of which may vary considerably, and, moreover, under the present practice of compiling weather data, these differences, some of major importance, could not be detected. The present unsatisfactory state of climatic analysis may be realized by comparing the conclusions of Barrell and Huntington in regard to the climate oscillations in regions outside the ice-sheets during the glacial epochs. Barrell suggests that in certain regions increasing cold may increase rock disintegration, without a corresponding increase in the transporting power of the streams, and therefore the outwash deposits may have been built up steeper as a response to the increasing cold of the glacial period, and on swing to a warmer climate there was erosion.[1]

Huntington explains that in the arid regions of Asia the moist (glacial) epoch accelerated the weathering of rock and growth of vegetation. Therefore waste was stored in the upper valleys of the mountains. Aridity followed with torrential precipitation and the destruction of vegetation, therefore the stored material was washed down on to the bajadas, and later, the supply from above giving out, these outwash deposits were dissected. Therefore each swing from glacial to interglacial is represented by a terrace.[2]

In reaching these different results in regard to the glacial-interglacial swing in elevated subarid regions, different sets of critical factors are assumed. It is not unlikely that both assumptions are correct and that the variations in different factors occurred at different times. It surely therefore is profitable to find out if possible what factors are of quantitative importance, and what range of play is possible between them.

[1] *Op. cit.*, pp. 172, 173. Barrell applies this to the dissection of the Gila Conglomerate. The author has reached a different conclusion which he hopes to present in a later contribution.

[2] *Op. cit.*, pp. 357, 358.

We must assume that there are certain areas of the globe which have had a dominantly arid climate as long as the atmospheric and oceanic circulation and the shape and relief of the continents resemble that of today. Doubtless those tracts whose arid condition is due chiefly to the trade winds have had a more continuous and a more steady arid history, than the deserts of the northern regions due mainly to topography. We have had the curious anomaly in the development of a geological philosophy during the last twenty years permitting, on the one hand, the upthrust of a continent thousands of feet, on the evidence of a slightly river-scarred plain, and, on the other hand, an almost universal assumption of climatic constancy, that could not possibly exist in view of the movements involved. Fully as curious are the physics involved in the earth movements necessary to make the lakes hold water, and then discharge the same again, in which the shifting piedmont and outwash deposits (erroneously interpreted as lacustrine) have been assumed to be laid down.

In the bolson region it is believed that if only there is a general dominance of arid conditions, a very considerable swing from arid to humid and back again is permitted. The through drainage of the moister climates has had great difficulty in cutting through the great talus and rock slopes which aridity has carved and built up into undrained basins.

While aridity depends primarily on deficiency of precipitation, variations in the same may take place along the following lines:

TYPES DEPENDING UPON THE DISTRIBUTION OF PRECIPITATION

Type 1. Torrential concentration of rainfall: (*a*) with moderate rainfall; (*b*) with deficient rainfall.

Type 2. A distributed and gentle rainfall, moderate in amount.

Type 3. A distributed and gentle rainfall very deficient in amount.

Torrential concentration.—The importance of torrential precipitation need not be investigated here. All writers are unanimous in giving it an important rôle. The general assumption seems to be that torrential concentration increases with aridity. It should be emphasized, however, that we have not the observational data to properly gauge this factor. The weather bureau arranges its data along *average* lines. Average daily, weekly, monthly, yearly tables

are given and doubtless later we will be told the average of the century. A knowledge of the average precipitation tells us little. The observations should also be arranged to determine the density of the precipitation, the unit taken being a rate of fall measured in centimeters per hour, then the figures for the rate of fall of each shower, or the most violent portion of the same would furnish some numerical foundation for further deduction. The assumption that increasing aridity always involves increasing torrentiality is not wholly justified, for conditions can be set up deductively which will cause an increasing precipitation of increasing torrential character.

In this preliminary analysis, therefore, torrential concentration is chosen as the first of the important factors governing desert climates. Livingston reports[1] that summer rains in Tucson often reach the amount represented by 1 cm in ten to fifteen minutes, and I estimate that, under the conditions that there obtain, a density of 3 cm per hour can probably be considered the lower limit of torrential precipitation.

The climate of the Salton Sink and San Felipe desert in Lower California is a good example of Type 3. MacDougal states[2] that the rainfall is distributed through the year so that only a small precipitation is received within any one month, and that at the Raza Islands no precipitation occurred for more than an entire year. At Fort Yuma the average for twenty-six years is 2.84 inches per year, with a fairly even monthly distribution, excepting a notable decrease for April, May, and June. This region shows to a marked degree the increased importance of wind action, and the extensive slopes are of gentler gradient than those developed under more torrential conditions. Without carrying analysis farther it is safe to conclude that under a non-torrential and distributed precipitation, the main quantitative factor is the increase in the relative importance of the wind action.[3]

If now rainfall increases moderately without decided torrential concentration, it is probable that vegetation, especially the grasses and the forests, will increase in importance, and the material of rock disintegration is held back, chemical weathering starts, talus slopes

[1] *Loc. cit.* [2] *Op. cit.*, p. 43.

[3] See Douglass, *The Crescent Dunes of Southern Peru* (in press); (Tolman, "The Crescentic Dunes of the Saltan Sea," *Jour. of Geography* (in press).

decrease in inclination, and also are protected against removal by grasses.[1] Here then the factor of increasing importance is the protective sheet of vegetation.

Effect of temperature.—Here again the extreme *daily* difference in temperature at the naked rock surface is desired, and the abundant data compiled from observations taken under shelters, etc., are of little value. Further, in the attempt to discover those factors of primary importance, all changes of longer period may be overlooked. Where the freezing-point is crossed daily, we probably have one of the maximum points in temperature change action, and where the rock surface remains above or below freezing for more than a day, the effect is diminished.[2] Here again there is a chance to gather further information, at moderate outlay of trouble, by placing self-recording thermometers on exposed rock surfaces, at different altitudes and times of the year in desert regions. It is evident that daily temperature is a variable, at least partially independent of the distribution of the rainfall, and after data have been collected its separate analysis as a climate factor should be attempted. Summing up we find that the following varieties of desert climate are important:

Type 1. Torrential Precipitation Dominant

Torrential distribution...	A—extreme or B—moderate	in either case with daily temp. diff.	*a*) extreme or *b*) large

Type 2. Protective Plant Covering Controls

A moderate and distributed rainfall with no great extremes of daily thermal change.

Type 3. Wind Action Important

A thin distributed rainfall grading to no rainfall.	and daily temp. difference	*a*) extreme or *b*) large

DEPOSITS OF THE BOLSON

The Bajada Outwash. Inclination.—In the moderate torrential conditions of southern Arizona, the middle portion of the slopes varies from 50 to 300 feet per mile. The grade of this middle portion appears remark-

[1] Johnson, *op. cit.*, p. 625.

[2] See Barrell, *op. cit.*, p. 172, for a summary not entirely in accord with the above and for a list of authorities; also C. and C., *Geology*, Vol. I, pp. 44–48, and MacDougal, *op. cit.*, pp. 77–79.

able even to the eye, and shows on the topographical maps by the even spacing of the contours. The grade increases on approaching the rock surface, and in extreme cases, especially where the slopes lead up to volcanic hills where undersapping by wind is prominent, it approaches the angle of repose for the material of which it is composed. It is distinguished from the upper margin of lake and ocean deposits by the absence of wave-built and wave-cut terraces, and the flat upper surface of the top set of the delta, etc.

Upper limit.—The line traced by the contact of the detrital material with the rock surface invariably extends up every gully and down around every ridge. With lake or ocean deposits a level upper line is scarred into the landscape by beach and cliff action.

Size of material.—The astonishing size of the boulders found in the outwash, with other phenomena described later, has led to a local popular appeal to glacial action. Boulders up to six feet in diameter are found in the Catalina and Santa Rita outwashes near Tucson, for a distance of half a mile from the present rock surface, and boulders at least two feet in diameter six miles and more from the present ranges. In ocean deposits occasional distribution of material of this size below cliffs only is noted.

Shape of boulders.—They are generally subangular, although some are partly rounded by their tumultuous journey.

Decomposition of the material.—Almost no decomposition of either boulders or smaller material was noted in the various bajada deposits examined; so much so that grave difficulty is encountered when attempting to account for the large amount of calcareous cementing material often present.

Sorting.—Layers of sized and clean sorted boulders, gravel, and sand are discovered but more often sorting is completely lacking, although stratification is always excellently developed. Pebbles are found in a matrix of sand, and boulders in a matrix of clay. In extreme cases the latter may not be due to water action. For instance, about two miles northwest of Travertine Point, Salton Basin, California, talus deposits, remnants of old slopes, were filled in with wind dust, and proved treacherous to climb. This is a deposit formed under extreme conditions of great daily temperature change and small non-torrential precipitation.

Arroyo trains.—The larger streams often run, for a portion of their course, at least, below the surface of the bajada, and nevertheless their work may be on the whole aggradational. Down such channels the streams bring large boulders, forming extensive radial deposits of rock trains.[1]

Sand pockets.—In the larger stream bottoms, especially in the cross drainage when developed at the foot of the bajada, deposits of perfectly sorted sand occur in "whirl pockets" sometimes composed of clean mica, forming then bad quicksand deposits.

Changes in layers.—The shifting character of the aggrading streams records itself in the rapid wedging-out of the layers. This is especially well shown in Tucson well sections where the boulder layers in adjacent wells do not occur in the same place in the column.

[1] Tolman, "Notes on Desert Processes and Desert Deposits," *Journal of the Proceedings of the Annual Convention of the Arizona Miners Association*, 1905–6, p. 15: "The distribution of coarse material in the outwash desert deposits is in some ways remarkable. The larger stuff is, of course, somewhere in the vicinity of the mountains. It is also distributed to great distances down the temporary torrent channels. To appreciate what is accomplished in these waterways at a distance from the mountains, it is necessary for one to have seen some such a display as I once witnessed on the desert plain between Altar and Puertocito on the road to Santa Ana, Sonora, Mexico. I was driving with no thought of rain, when suddenly I came to one of the numerous washes that cross the road, and found it filled to the brim with a foaming roaring flood, which was as impassable as the Niagara. Looking towards the mountains perhaps ten or fifteen miles distant, I noticed for the first time the black speck of the cloudburst, which happened to be at the headwaters of this arroyo and no other. In a few hours I was able to cross, and on my return found some boulders to approach three feet in diameter. And this was ten to fifteen miles distant from the mountains! On the west slope of the Santa Rita mountains (east of Tucson) there is a ridge of rocks that was piled there by a torrent which later took a different course. These large boulders have remained invincible against the subsequent attacks of the water. This deposit has been mistaken for the moraine of an old glacier. . . . . The rate at which the mountains are torn down and the outwash deposits are built up, is rapid indeed when compared with the slower processes of ordinary erosion. As an example of this rate I shall mention the fact that the bottom layer of the Tucson outwash deposit, south of the Santa Catalina mountains, contains fragments of porphyries and lavas which do not appear in place on the south side of the range. The conclusion is evident that this layer represents a portion of the mountains entirely washed away. . . . . Sometimes great boulders are found at some distance from the mountains. I recall one case where, between a great boulder and the parent mass from which it had been detached, there was a short ridge or knoll fifty feet high. I was asked how the boulder could have traveled up over the hill to its present position without the aid of ice. I answered 'the surrounding country has been washed away and the hill left as a remnant, since the boulder rolled down from above.'"

Stratification.—The stratification in outwash deposits is especially developed. The alternate floods, of varying volume, now carry mud and now boulders, both depositing. Also the wind action described sorts out a protective layer of larger pebbles. The crusts develop a more or less stratified form, especially where the surface is level. This is, however, modified by a dome structure, due to the drying-out of the slightly elevated portion, causing a capillary flow in that direction, and accentuated by a slight erosion of the hollows.

Playa deposits.—The deposits of the playas vary considerably especially as they are formed (1) under a water sheet of moderate depth; (2) in a thin sheet as an evaporating mud surface; (3) as a flood-sheet deposit from a strong flow from above; and (4) these are all modified by wind erosion during periods of aridity. The strata deposited under lacustrine conditions need not be considered here, as the details of such deposition have been under geological observation for many years. An excellent summary of the details is found in Barrell's articles, cited above. Summarizing some of the points of especial import, the following are noted: (1) The strands and terraces of inland water sheets comprise some of the first of the climatic criteria discovered by geology; (2) coarse material is distributed in belts, parallel to the strands, and found only in their vicinity; (3) the deeper muds are largely wind-borne, and therefore of even fineness; (4) lack of subaerial markings of all kinds, within the body of the deposit, as well as of oxidation, are the chief features separating lacustrine from playa and subaerial delta deposits; (5) thick beds of pure sorted mica, floated out into deep water (observed in the Painted Canyon series, Mecca, California), indicate deep-water deposition under arid conditions.

On account of the lack of dissection of the playas visited, less data have been gathered on this subject than on the others.[1] Some of the characteristics have been inferred from observations on playas in the making.

Chemical deposits of the playas.—The chemical deposits of the playas are the more soluble salts, while that of the lower portion of the surrounding bajada is largely carbonate of lime.

Playa mud. Subaerial characteristics.—The well-known markings

[1] For characteristics discovered by Huntington in Turkestan, see *op. cit.*, p. 286.

due to the drying of a mud sheet show extreme development here. Wind, sand, and salt often comprise the filling of the mud cracks. *Mud crack tubes.* At the margin of the Salton Sea the drying-out of irregular mudcracks develops a surface crust of salt, arching over the crack. When well developed these become perfect tubes, and simulate the salt crusts deposited around small roots, or even fossil tubes of worm burrows. *Shallow channels caused by wind erosion* were excellently developed on the Salton beaches, and might find preservation in fossil playa deposits. Where the playa develops alternate extended and lacustrine conditions, restricted with well-developed beaches, dune formations, and blown-sand deposits, with plunging and truncated structure, invade and cover the playa muds. Special development of dune and standing-water action was noted in the area of the Crescentic Dunes, Carrizo Sands, Salton Basin, which explains some irregular structures showing fragments and lenses of wind sand in shale, noted especially in the Painted Canyon series, Mecca, and deserves, perhaps, at least a passing notice. Between the individual dunes, the ground is strewn with rock fragments, composed largely of pieces of strongly cemented dune sand, and protruding above the surface is a most irregular wind-sand formation, also cemented. Its irregular truncations and bevelments showed plainly that it was built up of truncated bottom layers of dunes that had passed over, leaving behind their bottom layers, captured by the salt seepage water, and later cemented by limonite, the whole formation showing the extreme conditions under which it was formed.[1]

Animal remains in playas.—Judging from the large number of bogged cattle that perish in the Arizona "cienegas" (fresh-water mud flats) during periods of drought, the same ought to be expected in older playas. Salt water would not attract the animals. The wind-rows of decaying fish that occur after flood intervals, in the Laguna Maquata, described and explained in the following quotation, are suggestive in connection with the development of petroleum, in strata deposited in arid regions suffering from periodic invasion by a strong river or the sea.

This low ridge of dead fish was seen to extend for about 15 miles and may have been double that length. A similar observation was made by Orcutt in

[1] Tolman, *loc. cit.*

1890, who found that the remains at that time were of mullet. From other sources it seems fairly probable that nearly every flood brings with it shoals of fish which find their way into the laguna. The shallow sheet coming in over the plain to the southward must furnish abundant food: but as the water rises in temperature and increases in concentration, it seems quite probable that a point is reached at which the water becomes poisonous to all of the finny inhabitants. Furthermore, this condition ensues at once and with sweeping effect, for the dead fish go ashore during so brief a period that no marked change of level has taken place; and as evaporation may be as great as half an inch a day, and scarcely ever is less than a quarter, the disaster must take place within a week or two.[1]

Plant remains.—There is a decided dearth of fossil remains on both bajada and playa deposits. In regard to the former this is to be expected, due to complete oxidation and lack of exploration. The playa deposits, especially the fresh-water playas, and the cienegas of the semi-bolsons would be expected to contain more in spite of subaerial exposure, for wood decay is extremely slow in arid regions, and the dense clay ought to help preserve the more resistant portions of the plants, such as the sahuaro ribs and such hard woods as mesquite. The prompt decay of the mesquite wood which was immersed under the expanded Salton Sea, and now exposed, suggests that even a small amount of salt dissolved hastens decay, for the Salton water contained (June, 1907, about 2½ years after the first break of the river into the basin only) about four times as much salt as the Colorado River at low water, and even now it is possible to drink the water under stress of necessity.[2] An interesting problem demands solution as to whether or not the Tertiary deserts were more deficient in plant covering than those of today.

Erosion of the dried playa.—This is entirely by wind action. The smaller the playa the more likelihood of desert pavements, on account of the larger proportion of pebbles contributed by the floods from above. Such fossil wind-erosion surfaces have been noted in deposits examined.

Relative importance of lake and outwash deposits.—A brief reconnaissance in the Salton Basin gave a good chance to compare the relative importance of the lake deposits, and those laid down in the bajadas. This basin has suffered many invasions by the river water,

[1] MacDougal, "The Desert Basins of the Colorado River," cited above, pp. 16, 17.

[2] For analyses, see MacDougal, *op. cit.*, p. 3.

each time forming a "sea." Many of these seas were sufficiently long-lived to develop excellent strand phenomena, and yet the basin, over which these advances and stays of the water took place, shows a most insignificant proportion of lake deposits compared with the detrital outwash from the mountains. It is little wonder that the early explorers, attributing all the depositional work to stan.ing water, formed a very erroneous idea of the relative importance of lake deposition, and extended the sphere of its action far beyond that warranted by facts.

EFFECT OF CLIMATE ON THE EROSION OF THE BAJADAS

Turning again from facts to theory, let us investigate the effect of climatic variation on the erosion of the upper margin of the bajada. Space forbids a discussion of all the possible variations of climate on desert erosion, and moreover the profit resulting from such a theoretical discussion is very problematical. Even the limited investigation presented is more for the purpose of showing how

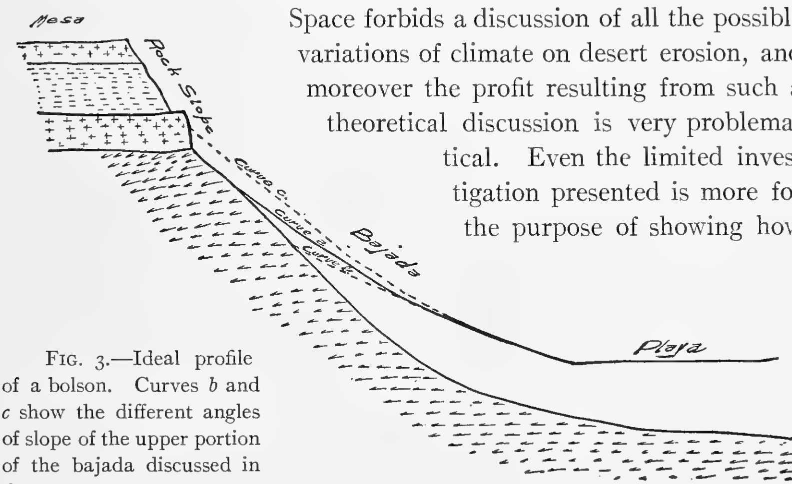

FIG. 3.—Ideal profile of a bolson. Curves *b* and *c* show the different angles of slope of the upper portion of the bajada discussed in the text.

complicated are the relations obtaining, and to emphasize the quotation which appears at the beginning of this article, rather than to develop working criteria.

Assuming that a playa is unaffected by earth movements that might displace it relatively to the surrounding bajadas, or by erosional attack of through drainage discharging to a lower level, a gullying from top to bottom would hardly be expected, and a minor incision especially of the upper portion would be more common. The initial slope is profiled by curve *a*, Fig. 3. Curve *b* shows the equilibrium

line with a lower angle of slope, a state of affairs that will result in the gullying of the bajada, while curve *c* indicates a condition that would result in rapid deposition. That such an erosion of the upper edge takes place irrespective of the conditions at the foot of the slope, is indicated by the fact that there are gullies which develop in the upper slope, but fade out before the bottom of the outwash is reached. Furthermore, an important criterion is discovered at this point. Should the bajada be gullied sharply from top to bottom, the cause may well lie in some change affecting the level of the playa, or the outwash drainage of the semi-bolson. North of Tuscon, in the Santa Catalina Mountains, there are remnants of an older and much higher bajada, than the well-developed lower and gullied slope. Preliminary studies suggested that this erosion might be connected with climatic change, but later it became evident that this was directly connected with the drainage developing at the foot of the slope.

Theoretical analysis, then, teaches us to look for variations of climate written in the upper slopes of the bajadas. The following is a list of those that ought to be most easily recognized:

Change in daily temperature difference variable, other factors remaining constant.

Change in torrential concentration variable, other factors remaining constant.

Change in plant covering variable, other factors remaining constant.

More effective still would be the immediate result of a decided swing, say from an effective daily temperature difference, to a marked torrential concentration, or the destruction of a heavy plant covering by aridity and a torrential concentration. Such possible factors were considered in attempting to explain the formation of the decided gullies that issue from the larger canyons of the Santa Catalina Mountains, and have incised the recent bajada,[1] but on close consideration it seemed more probable that these could best be explained by the fact that they drain a large area back in the mountains. The higher watershed receives more of the non-torrential winter rains, while the lower lands receive a larger proportion of their precipitation in the summer months and of a markedly torrential variety. The winter streams maintain a constant flow for several months, and are

[1] See the Topographic Map, Tucson Quadrangle, Ariz., V. S. G. S.

underloaded, and therefore slowly cutting. This erosion would be increased merely by increasing the proportion of winter precipitation to the whole.

Some idea of the delicate balance between climate and geological processes is gathered, when one considers that a slight shifting of the precipitation from the summer to the winter seasons produces a marked effect in erosion. Furthermore, differences in rock structure are more reliable as records of past climate than erosional features, so full of double meaning. Further investigation into possible criteria of climate change will not be undertaken here, although all the criteria suggested by studies so far have not been exhausted. If I have suggested some of the possibilities of the final results of this study, some of the working methods to be applied, some of the points that call most urgently for investigation, and some of the results that may finally be expected, the purpose of this contribution will have been fully accomplished.

THE WAVERLY FORMATIONS OF EAST-CENTRAL KENTUCKY[1]

WILLIAM CLIFFORD MORSE, Columbus, Ohio
AND
AUGUST F. FOERSTE, Dayton, Ohio

During a part of the summer just closed, the authors of this paper were engaged in working out the sub-Carboniferous stratigraphy of East-Central Kentucky for the state survey. The area covered extends from the Ohio River at Vanceburg southwestward seventy miles to the Kentucky River at Irvine. The results obtained, especially in the lower Waverly, are of sufficient interest, it is thought, to warrant publication.

The term Waverly was first applied to a series of rocks in Ohio. Under it are now included all of the rocks from the top of the Ohio shale to the base of the sub-Carboniferous limestone. In central Ohio the series has been divided into six formations, based upon their lithological characters. These formation names will be used, as far as possible, in the Kentucky field. They are, in descending order:

6. Logan formation.
5. Black Hand formation.
4. Cuyahoga formation.
3. Sunbury shale.
2. Berea grit.
1. Bedford formation.[2]

In the southern part of Ohio, however, the conglomerate phase of the Black Hand is not developed as it is in the central part. This makes the division of the upper Waverly into the Black Hand and

[1] Published by permission of Professor Charles J. Norwood, director of the Kentucky Geological Survey. Presented at the eighteenth meeting of the Ohio Academy of Science, Granville, November 28, 1908.

[2] C. S. Prosser, "The Classification of the Waverly Series of Central Ohio," *Jour. Geol.*, Vol. IX, pp. 214, 215, 1901. That the line of division between the Carboniferous and Devonian systems is still in doubt may be seen by referring to Professor Prosser's paper, "Revised Nomenclature of the Ohio Geological Formations," *Geol. Surv. Ohio, Bull. 7*, pp. 2, 17–21, 1905.

Logan practically impossible since the rocks, beginning with the upper Cuyahoga, are lithologically very similar. This is true also of the Kentucky field.

The lower formations, the Bedford, Berea, and Sunbury, and also the lower part of the Cuyahoga, on the contrary, are quite constant in this part of the state. They have been traced as far south as the Ohio River. Professor Prosser in the preparation of his paper on "The Sunbury Shale of Ohio" pushed the line just across the river and made a section at Vanceburg, Ky.[1]

Shortly after leaving the Ohio River, however, the Bedford and Berea rapidly thin out, allowing the Sunbury shale to rest almost directly upon the Ohio shale. The sandstones of these lower formations also disappear and are replaced by shales. There is also a marked westward thinning.

The discovery of these facts has contributed materially to the correct determination of the Waverly formations of eastern Kentucky. The presentation of these data together with their bearing upon the stratigraphy will form the chief part of this paper. This, probably, can best be accomplished by giving in order a few sections which clearly show the changes.

At the southeastern end of Vanceburg is a high hill known as Alum Rock. Along a path ascending this hill the rocks are nicely exposed from the Ohio shale to the lower part of the Cuyahoga. Since this section is one of the most typical of the lower Waverly in Kentucky, it will be given somewhat in detail, although it has already been published.[2]

SECTION OF ALUM ROCK, VANCEBURG

	Feet	Inches	Feet
5. *Cuyahoga formation*..............................			39
Interval covered except a thick layer of argillaceous sandstone at the top. The sandstone contains *Taonurus*. Small phosphatic nodules are found in the basal part of the interval.			
4. *Sunbury shale*, total thickness........................			15½
Black, fissile, carbonaceous shales, which cannot be distinguished, lithologically, from the Ohio shale.			

[1] *Jour. Geol.*, Vol. X, pp. 292, 293, 1902.

[2] *Loc. cit.*

3. *Berea grit*, total thickness			$22\frac{1}{4}$
Thick layer of gray sandstone	2	6	
Heavy layer of rather coarse-grained gray sandstone, the upper surface excellently ripple-marked	3		
Medium to thick-bedded rather coarse-grained gray sandstones, beautifully ripple-marked	15		
Arenaceous shales	1		
Layer of fairly coarse-grained gray sandstone		9	
2. *Bedford formation*, total thickness			$95\frac{5}{6}$
Blue arenaceous shales and shaly sandstones. Lower part slightly covered	35		
Arenaceous shales with thin sandstone partings	7		
Layer of thick-bedded gray sandstone	1	8	
Arenaceous shales with two layers of sandstone	6	9	
Heavy layer of gray sandstone, with lower surface contorted	2	4	
Arenaceous shales with two layers of gray sandstone	6	6	
Layer of thick-bedded buff sandstone	1	9	
Medium-bedded gray sandstones with shaly partings	2	10	
Arenaceous pink shales with sandstone partings	2	6	
Covered interval	5		
Layer of thick-bedded, buff sandstone	2		
Practically covered interval with some argillaceous shales.	22	6	
1. *Ohio shale*			242
Black fissile, carbonaceous shales. About ten feet from the top, one or two linguloid shells occur. Near the central part the shales become softer and lighter in color and resemble a similar zone in the Ohio at Columbus, (Ohio). The interval (242′) is mostly exposed and extends to the level of the Chesapeake and Ohio Railroad. At "Slate Point," however, the top and bottom contacts are shown and the total thickness is $301\frac{1}{4}$ feet.			

The most striking feature of this section is the development of sandstones within the Bedford formation, which usually consists of shales alone. This feature recalls a similar development in northern Ohio. Along Euclid Creek, east of Cleveland, sandstones occur in quite regular layers at about the same horizon, and are extensively quarried. They are known to the trade as the Euclid stone and the division has been appropriately named the "Euclid lentil" by Professor Prosser.[1]

[1] Used in a manuscript not yet published.

Alum Rock hill extends only a short distance, 39 feet, above the Sunbury shale and this interval is practically covered except at the top where a massive layer of sandstone is exposed. Higher strata are found, however, in an adjacent hill known as "Slate Point." Near the summit the lower Cuyahoga is quite well exposed along the road which ascends the hill. It consist of even-bedded argillaceous sandstones or freestones with shaly partings and is the typical Buena Vista member.[1]

On the Petersville Road some three miles south of Vanceburg is a long hill known as the Vanceburg hill. After this is crossed, the Sunbury shale is found at its base, and below, 19½ feet of the top of the Berea grit. Instead of being a massive sandstone, as at Alum Rock, the most of this interval is composed of arenaceous shales and shaly sandstones, only 2½ feet reaching the proportions of a thin-bedded sandstone. The upper two feet have been considerably disturbed while the last layer varying from 0 to 9 inches is badly contorted. There was no question as to this identification, however, as the sandstones were excellently ripple-marked and were directly overlain by the complete Sunbury.

Such marked lithological changes in so short a distance are very striking and should cause subsequent study to be performed more critically. They also prepare us for, or cause us to anticipate, other changes.

At various places along the next six or eight miles of this same road, slight exposures show that the area has been somewhat disturbed. This is mostly in the form of folds and affects the top of the Ohio shale and the Bedford and Berea. In one place the movement was sufficient to cause a fault but the exposure was not large enough to show the amount of displacement.

Thirteen miles south of Vanceburg, at the home of J. E. Kegley, the Petersville Road crosses a small run called Elk Lick. At the road side south of this stream is a steep hill, upon the side of which the Ohio, Berea, and Sunbury are exposed. While the out-crops are not all that could be desired, yet they show that the Bedford and

[1] For the revival and present usage of the term "Buena Vista" and another, "City ledge," to be used later, the reader is referred to pages 341 and 342 of Professor Prosser's paper on "The Waverly Formations of Central Ohio," *Am. Geol.*, Vol. XXXIV, 1904.

Berea have thinned from 118 feet to a total not exceeding 75 feet in this distance.

ELK LICK CREEK SECTION

	Feet	Inches	Feet
4. *Sunbury shale.*			
Pieces of black, fissile, carbonaceous shale directly above the sandstone layers.			
3. *Berea grit*			75
2. *Bedford formation*			
Medium-bedded sandstones, ripple-marked on the upper surfaces. Unquestionably Berea	7	6	
Covered interval, which probably contains the contact of the Bedford and Berea	67	6	
1. *Ohio shale*			30
Black, fissile, carbonaceous shales, which extend down to the level of the highway at the spring.			

In the second gully west of the schoolhouse in Petersville, the strata are exposed more or less completely from the Ohio shale to the lower Cuyahoga formation. By combining the exposures of both branches of this gully, an almost continuous section is had from the top of the Ohio to the top of the Sunbury. This is the key section to the lower Waverly problem. The Bedford and Berea cannot have a total thickness of over $46\frac{1}{2}$ feet, showing a thinning of over 70 feet in 18 miles or nearly 30 feet in 5 miles. The sandstones, too, have also practically disappeared, leaving only the shales behind. Whether these belong to the Bedford alone or to the Bedford and Berea is still an open question as both formations contain sandstones at Vanceburg. If a section of about normal Berea, underlain by shales only, were obtainable somewhere in the vicinity of Elk Lick, then these $46\frac{1}{2}$ feet could be referred to the Bedford. However, such a section has not been and probably never will be found. The shales probably belong in part to the Bedford and in part to the Berea. If this be true they cannot be separated into the two formations from here southward and for the present, at least, they will be designated together under the inclusive term Bedford-Berea.

PETERSVILLE SECTION

	Feet	Inches	Feet
4. *Cuyahoga formation*			$55\frac{1}{2}$
Medium to heavy-bedded, gray, argillaceous sandstones with shaly partings	14		
Covered interval	41	6	

3. *Sunbury shale*, total thickness......................			$12\frac{1}{2}$
Black, fissile, carbonaceous shales.			
2. *Bedford-Berea*, total thickness......................			$46\frac{5}{12}$
Covered, except some arenaceous and calcareous shales, which are probably ripple-marked....................	14		
Bluish to buff arenaceous shales with an occasional parting, ripple-marked................................	17	6	
Blue, argillaceous to arenaceous shales with an occasional calcareous or arenaceous parting.....................	7		
Thin layer of sandstone............................		5	
Blue, argillaceous shales with a little black, carbonaceous shale at the base...............................	4	3	
Covered interval..................................	2	6	
Soft, argillaceous shales mixed with some black shales..		9	
1. *Ohio shale*..			85
Black, carbonaceous shales, slightly covered...........	85		
Covered, to the water level of Kinniconick Creek at the church..	10		

Near Fox Springs, Fleming County, an exposure shows a probable thickness of $32\frac{1}{2}$ feet for the Bedford-Berea. While the horizon continues to thin to the southward, the rate of decline is much more gradual than it has been in the area just discussed, and for this reason sections will now be given at longer intervals only.

In the highway leading up the hill at Rockville Station, Rowan County, is an excellent exposure from the Ohio shale to the lower Cuyahoga. The Bedford-Berea is only $18\frac{1}{2}$ feet thick, but probably the greatest value of the section is its aid in determining the true horizon of the sandstones quarried in this vicinity. These have been referred to the Berea grit by Hoeing,[1] but a glance at the following section will show that they belong to the Buena Vista member of the Cuyahoga formation. The Buena Vista sandstones with shaly partings are typically developed but the interval is only 37 feet as compared with 60 feet for the same member along the Ohio River west of Portsmouth, Ohio.

SECTION AT ROCKVILLE STATION

	Feet	Inches	Feet
Soil to the level of the peneplain......................	15		
4. *Cuyahoga formation*................................			90
Soft, blue, argillaceous shales with an occasional ferrugi-			

[5] *Kentucky Geol. Surv., Bull. I*, p. 49.

	Feet	Inches	Feet
nous parting. The lower two feet covered, but probably shales	35		
Soft, blue, argillaceous shales alternating with thin to medium-bedded argillaceous sandstones, the shales predominating	18		
Top of the Buena Vista member and also the top of the stone quarried. Even-bedded argillaceous sandstones, "freestones," with thin partings of blue argillaceous shales. The sandstones contain *Taonurus*. The layers are mostly medium-bedded, that is of proper thickness for commercial use. Their size together with the shaly partings render them easily quarried. They are quite extensively worked and make a beautiful and excellent stone	25	6	
Soft, blue, argillaceous shales with three or four shaly sandstone partings, which contain *Taonurus*	4	6	
Soft, blue argillaceous shales	7		
3. *Sunbury shale*, total thickness			16¼
Black, fissile, carbonaceous shale.			
2. *Bedford-Berea*, total thickness			18½
Soft, blue, argillaceous and finely arenaceous shales, and fine-grained shaly sandstone. The lower two feet have one or two thin layers of black, fissile shale.			
1. *Ohio shale*			20¾
Black, fissile, carbonaceous shales	2		
Covered to the level of the Chesapeake & Ohio Railway Exposures in a nearby gully and the main stream show, however, that all of this interval is Ohio shale	18	9	

Quite a variation in the thickness of the Bedford-Berea occurs along an east-and-west line at Olympian Springs, Bath County. This variation will be given here to prepare us for the remarkable thinning farther southward. Two sections were made within a radius of a mile of the Springs. In the eastern of these the horizon measured 12½ feet, in the western 5¾ feet, while on the opposite side of the hill from the latter and a half mile farther west, the thickness was only 2 inches. The Sunbury on the contrary was quite regular, measuring 12⅓, 12¾, and 12 feet for the respective sections.

From Olympian Springs southwestward, at least on the western border of the Cuyahoga outcrops, the sandstone layers of the Buena Vista member begin to gradually disappear. By the time Jefferson-

ville, Montgomery County, is reached, only a single layer remains. It occupies the position of the lowest, but whether or not it is one and the same layer or different layers at the various exposures to the southward cannot be determined. From its position in the following section, which was taken one mile east of town, it will be seen to occupy the position of the "City ledge."

SECTION AT SLATE CREEK BRIDGE, JEFFERSONVILLE

	Feet	Inches	Feet
4. *Cuyahoga formation*			$5\frac{1}{12}$
Layer of massive, argillaceous sandstone with *Taonurus* abundant. In this vicinity exposures are sufficient to show seventeen or eighteen feet of argillaceous shales above this layer	2	10	
Soft argillaceous shales	2	3	
3. *Sunbury shale*, total thickness			11
Black, fissile, carbonaceous shales.			
2. *Bedford-Berea*, total thickness			$4\frac{1}{6}$
Bluish to dark, slightly ferruginous, argillaceous shales.			
1. *Ohio shale*			$31\frac{1}{2}$
Black, fissile, carbonaceous shale to the base of the exposure	31	6	
Black shales extend to the level of Slate Creek at the bridge, but these were not measured.			

Still farther south the lower layer finally disappears. In place of the Buena Vista sandstones, soft, argillaceous shales occur in the lower Cuyahoga. To these clayey shales, August F. Foerste applied the term "Linietta clay," provisionally, before their identity with the New Providence shale of southern Indiana was ascertained.[1] The New Providence shale with the overlying Riverside sandstone, it will be recalled, make up the Knobstone formation of Indiana.

About Indian Fields in Clark County, the Ohio shale extends to near the top of the hills. One mile east of the station, along a highway passing within a quarter of a mile of Oil Springs, the following section was taken. The chief interest in this one is, that while the Bedford-Berea is only two inches in thickness, the shales are fossiliferous. More will be said about these fossils after the Irvine section has been given.

[1] *Kentucky Geol. Surv., Bull. VII*, p. 14.

SECTION AT INDIAN FIELDS

	Feet	Inches	Feet
3. *Sunbury shale*			$9\frac{1}{4}$
Black fissile, carbonaceous shales.			
2. *Bedford-Berea*, total thickness			$\frac{1}{4}$
Fossiliferous, argillaceous, and calcareous shales.			
1. *Ohio shale.*			
Black, fissile, carbonaceous shale extending down the hill for a long distance but not measured.			

An instructive section is seen one mile northwest of Stanton, Powell County, in a lane leading up to the residence of Lewis Foulkner.

SECTION AT STANTON

	Feet	Inches	Feet
4. *Cuyahoga formation*			$4\frac{1}{4}$
Soft, blue, argillaceous shale not measured.			
Layer of buff, fine-grained, calcareous sandstone, which weathers into large flat nodules	1	3	
Soft, blue, argillaceous shale	3		
3. *Sunbury shale*, total thickness			$6\frac{1}{2}$
Black, fissile, carbonaceous shale.			
2. *Bedford-Berea*			$\frac{7}{12}$
Bluish, argillaceous, and calcareous shales.			
1. *Ohio shale*			$16\frac{1}{2}$
Black, fissile, carbonaceous shale	16	6	
Covered to the highway	19	9	

The final section is from Irvine, Estill County. Here the Bedford-Berea is 1 foot, 6 inches in thickness and fossiliferous, while the Sunbury is only 3 feet. This very gradual decrease in the Sunbury should be noted although it is much less marked than the thinning of the Bedford-Berea.

SECTION OF MINERVA MOUNTAIN, IRVINE

	Feet	Inches	Feet
6. *Sub-Carboniferous limestone*			1
Yellowish, sandy-like limestone, lying at the extreme top of the hill.			
5. *Upper Waverly series*, not divided			344
Covered interval	60	6	
Thin bedded, buff, argillaceous sandstones, which weather to thin shaly pieces, *Taonurus*	17		
Layers of massive, buff, argillaceous sandstone, *Taonurus* abundant	24		

Buff, argillaceous sandstones, weathering to shales. *Taonurus*	17		
Covered interval	225	6	
4. *Cuyahoga formation*, top not determined			144
Brownish, ferruginous, and calcareous, nodular layer of sandstone		6	
Indurated, bluish to pinkish, argillaceous shales with ferruginous, nodular layers	69	6	
Soft, bluish, argillaceous shale with ferruginous, nodular layers, slightly covered (top of Linietta clay)	63	6	
Layer of brownish, argillaceous sandstone, which breaks up into shaly layers	2		
Soft, bluish to pinkish, argillaceous shales with small phosphatic nodules	8	6	
3. *Sunbury shale*, total thickness			3
Black, fissile, carbonaceous shales.			
2. *Bedford-Berea*, total thickness			1½
Argillaceous shales with phosphatic nodules		2	
Black, fissile, carbonaceous shales		3	
Dark, argillaceous shales, with some carbonaceous material		6	
Gray, calcareous, and argillaceous shales, slightly fossiliferous		2	
Yellowish, calcareous, and argillaceous shales, the upper part very fossiliferous		5	
1. *Ohio shale*			94½
Black, fissile, carbonaceous shales, with an occasional softer argillaceous layer. Practically all exposed to the highway.			

The thinning-out of these formations can probably be more clearly shown graphically. The sections that have just been described are grouped in the two accompanying figures, and follow each other consecutively.

Several of the fossils collected at Irvine and also at Indian Fields when compared with those from the base of the Bedford at Columbus, Ohio, prove to be the same species. Of these *Macrodon hamiltoniae* is the most abundant one common to both fields. This paleontological confirmation of the conclusion reached by a lithological study is surely gratifying.

It may be argued from this that the thin argillaceous horizon should be referred to the base of the Bedford rather than to the Bedford-

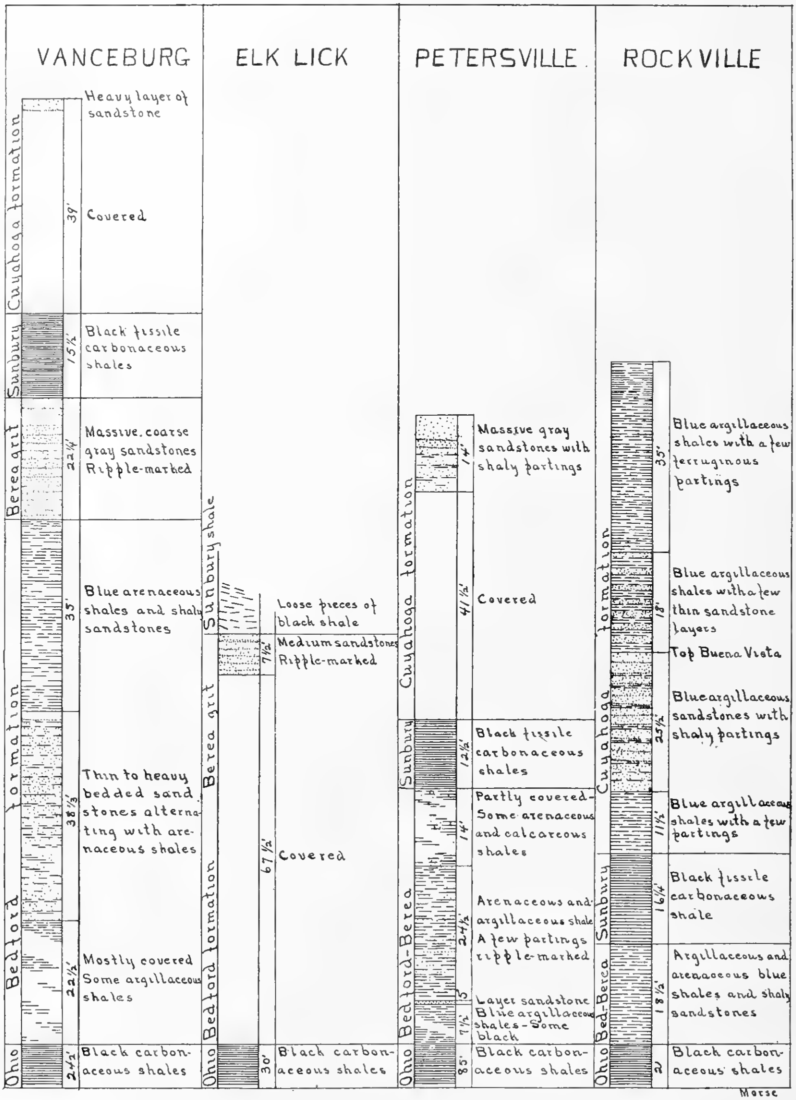
VANCEBURG
ELK LICK
PETERSVILLE
ROCKVILLE
Cuyahoga formation
39'
Heavy layer of sandstone
Covered
Sunbury
15½'
Black fissile carbonaceous shales
Berea grit
22¼'
Massive. coarse gray sandstones Ripple-marked
Bedford formation
35'
Blue arenaceous shales and shaly sandstones
38⅓'
Thin to heavy bedded sandstones alternating with arenaceous shales
22½'
Mostly covered Some argillaceous shales
Ohio
24½'
Black carbonaceous shales
Sunbury shale
Loose pieces of black shale
Berea grit
7½'
Medium sandstones Ripple-marked
Bedford formation
67½'
Covered
Ohio
30'
Black carbonaceous shales
Cuyahoga formation
14'
Massive gray sandstones with shaly partings
41½'
Covered
Sunbury
12½'
Black fissile carbonaceous shales
Bedford-Berea
14'
Partly covered-Some arenaceous and calcareous shales
24½'
Arenaceous and argillaceous shale A few partings ripple-marked
3'
Layer sandstone
7½'
Blue argillaceous shales-Some black
Ohio
85'
Black carbonaceous shales
Cuyahoga formation
35'
Blue argillaceous shales with a few ferruginous partings
18'
Blue argillaceous shales with a few thin sandstone layers
Top Buena Vista
25½'
Blue argillaceous sandstones with shaly partings
11½'
Blue argillaceous shales with a few partings
Sunbury
16¼'
Black fissile carbonaceous shale
Bed-Berea
18½'
Argillaceous and arenaceous blue shales and shaly sandstones
Ohio
2'
Black carbonaceous shales
Morse

FIG. 1

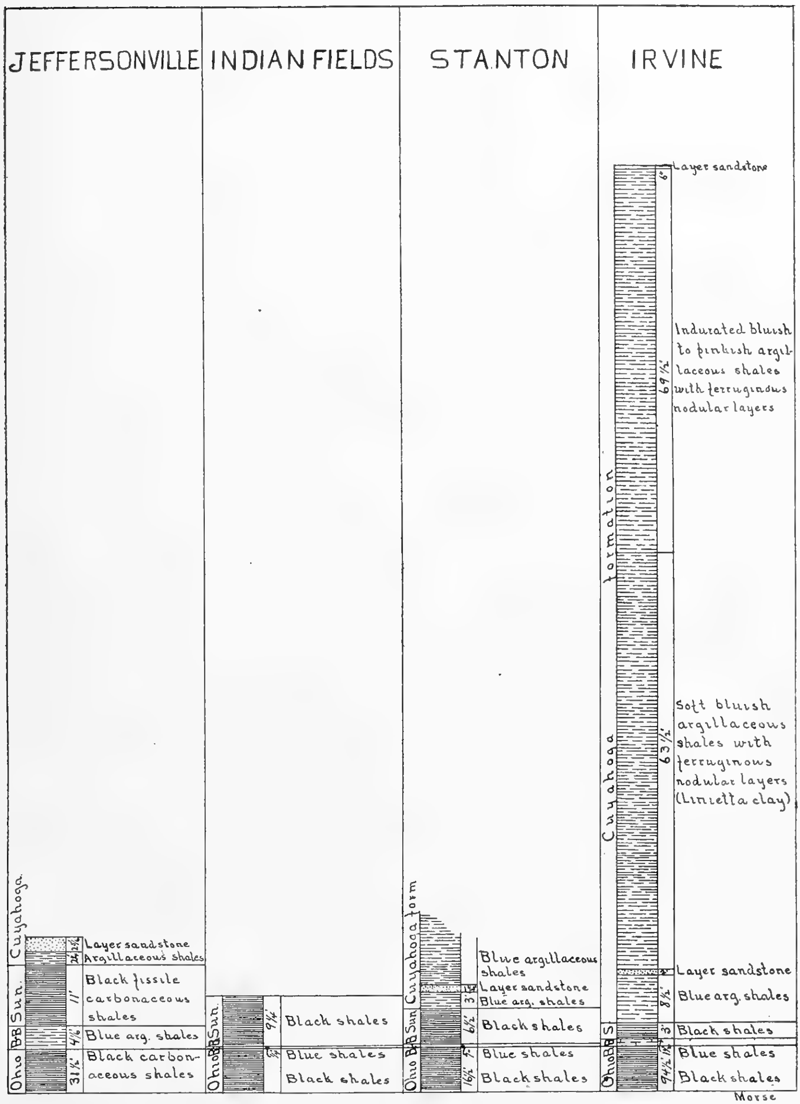
JEFFERSONVILLE
INDIAN FIELDS
STANTON
IRVINE
Cuyahoga
Layer sandstone
Argillaceous shales
Black fissile carbonaceous shales
Blue arg. shales
Black carbonaceous shales
Ohio
BB
Sun.
11'
4½'
31½'
Black shales
Blue shales
Black shales
9¼'
Cuyahoga form
Blue argillaceous shales
Layer sandstone
Blue arg. shales
Black shales
Blue shales
Black shales
6½'
16½'
Cuyahoga formation
Layer sandstone
Indurated bluish to pinkish argillaceous shales with ferruginous nodular layers
69½'
Soft bluish argillaceous shales with ferruginous nodular layers (Linietta clay)
63½'
Layer sandstone
Blue arg. shales
8½'
Black shales
Blue shales
Black shales
94½'
Morse

FIG. 2

Berea. This is a strong argument, yet from facts set forth above it seems advisable to refer the rapidly decreasing horizon to the Bedford-Berea.

In this connection, it might be well to give the conclusions reached by Professor Williams in his paleontological study of the black shales. He states that an

> examination of the sections at Irvine, Kentucky, the other side of the Cumberland channel revealed the fact that there the black shales were thinner but held on in their purity, well up into Carboniferous time. The intercalations consist of calcareous and ferruginous, concretionary sheets, and carry undoubted Carboniferous fossils and occur in the sections before the black shale loses its characteristic expression.[1]

These black shales have been correlated with the Ohio black shale in the various geological reports of the state. The geologists of the National Survey, approaching the field from the south, have, on the other hand, designated them as the Chattanooga shale.[2] Both have referred them, in their entirety, to the Devonian system. That they belong to both the Devonian and Carboniferous systems has, it is thought, been clearly demonstrated.

Of the London and Richmond Folios of the U. S. Geological Survey, the latter adjoins the Irvine field. In these Campbell has designated the clay shales and argillaceous sandstones, above the Black shale, as the Waverly formation. It is permissible, according to the rules of that survey, to reduce a series to the rank of a formation, but, as applied here, Waverly covers not more than the upper half of that division. The lower half, Bedford, Berea, and Sunbury, has just been shown to be included within the limits of the Chattanooga (Ohio) shale.

It is interesting to note that Professor Grabau anticipated this limitation. Referring to the London Folio, he states that:

> The shale above the Black (Ohio) shale is referred to the Waverly, of which it probably constitutes the upper portion only. As at Irvine, the transition from the Black shale to the overlying beds is probably a gradual one.[3]

This conclusion seems to have been reached deductively, from a

[1] *Am. Jour. Sci.*, 4th series, Vol. III, p. 398.

[2] Estillville, London and Richmond Folios, U. S. Geol. Surv.

[3] *Bull. Geol. Soc. Am.*, Vol. XVII, pp. 609, 610.

study of Professor Williams' paper which he quotes and to which reference was made above.

To summarize, then, it may be stated that: The Bedford and Berea formations thin rapidly southwestward from the Ohio River and this horizon, even after it has been reduced to a thickness of only a few inches, can be traced to near the crossing of the Cincinnati geanticline by the Waverly series.

The Sunbury shale, on the contrary, suffers but little decline, at least until Indian Fields is reached.

The Ohio black shale of the Kentucky reports or the Chattanooga shale of U. S. reports, south of Petersville, is not of Devonian age alone but of Devonian and Carboniferous, that is, is composed of both the Ohio and Sunbury shales, and a thin zone representing the Bedford and Berea.

The sandstones, which are extensively quarried about Rockville Station belong to the Buena Vista member of the Cuyahoga formation rather than to the Berea grit.

The Buena Vista sandstones begin to disappear from Olympian Springs southwestward except a single layer which, if not always the same, at least occupied the position of the lowest and which persists as far south as Stanton if not to Irvine.

The Linietta clays belong to the lower part of the Cuyahoga formation.

The so-called Waverly of at least the Richmond Folio includes only the upper part of the Waverly, beginning with the base of the Cuyahoga.

NOTES ON THE POINT HOPE SPIT, ALASKA[1]

E. M. KINDLE

Point Hope is a spit of gravel and shingle which extends out into the Arctic Ocean from the northwestern coast of Alaska, about one hundred and twenty-five miles north of the Arctic Circle. It marks the most westerly point reached by the continental shore line north of Kotzebue Sound. After Cape Prince of Wales it is the westernmost point of the continent. (See Fig. 1.) Point Hope extends seaward from the delta of the Kukpuk River and represents the northwestern extension of the barrier beach which curves southeastward to the cliffs at Cape Thompson, a distance of about thirty-five miles. The spit and the delta deposits behind it together extend out a distance of about fifteen miles beyond the bed-rock area of the original shore line. Lagoons and barrier bars are a common feature of the northwestern coast of Alaska, but spits extending out into the sea are unusual and the Point Hope spit is unique in being the only spit along this coast line which projects any notable distance into the sea at right angles to the coast line. Point Barrow and the long bar forming Point Clarence Harbor are the only spits on the northwestern coast of Alaska which are comparable in size with the Point Hope spit. Neither of these, however, shows the finger-like projection from the coast line of Point Hope, each of them curving toward the eastward. The natives have named this rather striking physiographic feature "Tigara," from its fancied resemblance to the index finger of the hand, which the word signifies.

Abo t one and three-fourths miles from its western extremity the Point Hope spit is joined by a bar which is only about one hundred yards in width at the point of junction with the spit. This bar extends in a northeasterly direction nearly to the mainland and forms with the spit a V-shaped figure inside of which are the shallow waters of Marryat Inlet and the delta of the Kukpuk River.

It will be seen by reference to the map (Fig. 2) that the unconsolidated beds which lie to the west of the area of bed-rock outcrops in the neighborhood of the mouth of Kukpuk River cover a rather extensive area. They represent in large part delta deposits and in part fore-

[1] Published by permission of the Director of the U. S. Geological Survey.

land and beach deposits. We are here concerned only with the latter. The delta deposits are easily distinguished as a rule and usually consist of interstratified silts and sands overlaid by fine black sediments

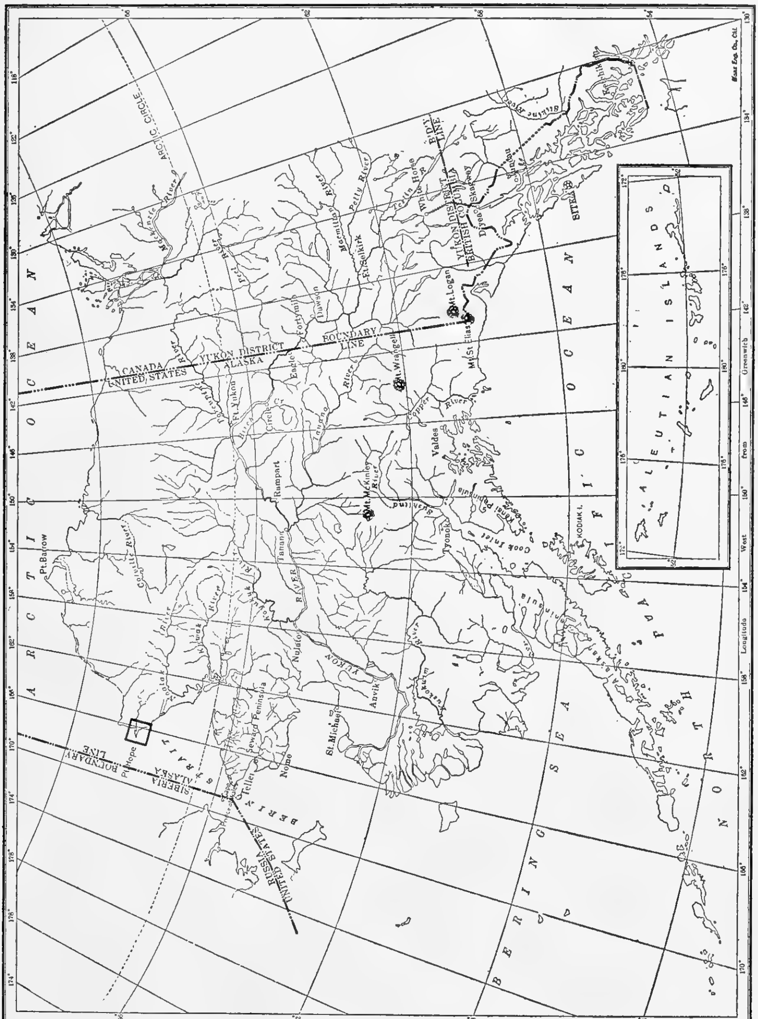

FIG. 1.—Outline map of Alaska, showing by rectangle the area of the Point Hope map.

which are often interbedded with peat-like accumulations of marsh grass turf.[1]

[1] Mr. A. J. Collier gives a brief description of the delta deposits in a report on the Cape Lisburne coals, *Bull. U. S. G. S., No. 278*, p. 33, 1906.

A regularly concave shore line connects the base of the spit with the cliffs of Cape Thompson from which most of its materials are derived. A narrow gravel barrier beach, frequently only 100 or 200 feet in width, forms the coast line of this concave beach, a distance of about 25 miles. Behind this beach is a series of lagoonal fresh-water lakes which drain by filtration through the beach. The beach is

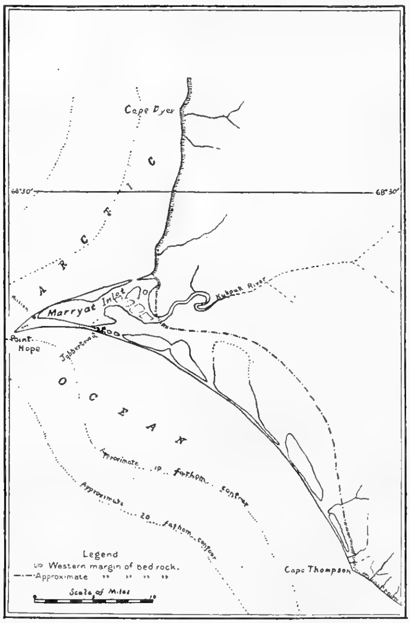

FIG. 2.—Reconnaissance map of Point Hope and adjacent coast line. By E. M. Kindle.

unbroken by streams entering the sea, except within the first mile to the west of Cape Thompson.

The south shore of the spit is generally steep, while the northwest shore is less abrupt. The point terminates abruptly in rather deep water, 13 fathoms being recorded a few ship's lengths from the tip of the point. Off the south shore the eight-fathom contour runs within a quarter of a mile of the shore toward the western end of the Point. On rounding the Point the soundings decrease rapidly to

five fathoms and a shoal with four fathoms at its southern end extends some three miles in a west-northwest directin from the Point.[1]

The materials composing the spit are much coarser than those of many spits. Much of it may be properly called shingle, while coarse gravel and a small proportion of sand comprise the remainder of the material. The coarser materials are composed of limestone and chert. From the point where the spit joins the delta deposits at Jabbertown to its western extremity, its length is about eight miles. The surface of the spit has an elevation ranging from thirteen to seventeen feet above the sea. Its greatest width is near the mission where it is about one mile from the north to the south side.[2] From this point it tapers gradually toward the east. It reaches its minimum width near its base where it is less than a quarter of a mile across.

An interesting feature in the make-up of the spit is a series of regular straight canal-like depressions trending nearly east and west and lying parallel with the south shore. The northwest shore line cuts these channels at an acute angle. The bottoms of the channels are depressed below the general surface of the spit from two to six feet. The shallower ones are entirely dry and would hardly be noticeable were it not for their distinct parallelism with the deeper ones. Water remains throughout the summer in two or three of the deeper ones, and it is from this source that the native village secures its water supply. In width these depressions will range perhaps between forty and one hundred feet, and the intervening spaces will average probably two hundred feet. The sides curve very gently into the surface of the interval separating them, which frequently is slightly convex. These canals all extend to the northwest beach, which cuts them off forming an acute angle with the north border of the depression. To the eastward most if not all of them can be recognized at least two miles from the western extremity of the point. Two of them are considerably deeper at this distance than farther west. Near

[1] Lieutenant D. H. Jarvis, "Coast Pilot Notes on the Fox Islands Passes, Unalaska Bay, Bering Sea and the Arctic Ocean as far as Pt. Barrow," *Bull. Coast and Geod. Survey, No. 40*, p. 56, 1900.

[2] As a basis for determining the amount of wave-cutting on the northwest shore of the spit by future observers, the distance from the north side of the mission observatory to the water line on the northwest beach was measured on a north and south (true) line and found to be 525 feet.

the base of the spit at Jabbertown most of these depressions have faded out. Observations on the bearing of each of these have shown that the four northernmost of the series differ from the others in direction several degrees and are parallel to the south shore of Marryat Inlet. The south shore of the inlet here bears about S. 73° E. Two of the first four canals south of it have the same bearing, while the other two bear respectively S. 74° and S. 75° E. The other canals to the south of these are nearly parallel with each other and with the south shore. Twelve of the latter have been recognized. The variation in the direction of these is within the limits of S. 83° E. and S. 90° E. Under the name of aggradation lines Dr. F. P. Gulliver describes what appear to be similar features in the Dars foreland in the Baltic Sea, Carraveral foreland, Florida, and other cusps.[1]

The writer's observations seem to establish two important facts relative to the present action of destructive and constructive agencies on the spit. The northwest shore is being cut away rather rapidly while the south shore is being built up. The ruins of an ancient Eskimo village, which is being undercut by the waves, afford indisputable proof of the encroachment of the sea on the northwest side. We have also the testimony of a missionary, Dr. John Driggs, who has resided for 18 years near the north shore of the point. He states that 185 feet would be a very conservative estimate of the amount of cutting which has occurred on the north shore during the period of his residence. He informed the writer that the cutting of the shore was accomplished almost entirely during the prevalence of heavy southwesterly or westerly storms. At such times the waves are driven along the beach and carry away its loose materials very rapidly. The writer was shown the door of the old mission chapel standing about sixteen feet above the sea and some two hundred and fifty feet from the beach which was smashed by wave action during a southwest storm of exceptional violence which occurred October 13, 1893. It appears that during this storm the sea was banked up on this coast until one to three feet of water covered nearly all the western portion of the spit.

The evidence that constructional work is in progress on the south side of the spit is based in part on the relative freshness of the gravels

[1] *Proc. Am. Acad. Arts and Sci.*, Vol. XXXIV, p. 180, 1899.

on the north and south sides and the comparative extent to which vegetation has secured a foothold on the two sides. A few varieties of grass, which constitute nearly the sole vegetation, extend everywhere along the north shore up to the limit of wave action. On the south side the gravel is fresh-looking and in many places is entirely barren of vegetation for two or three hundred yards from the shore.

It is interesting to note that the first white men to land on this point were impressed with the recent character of some of the deposits, comprising the spit. Mr. A. Collie, who was a member of the scientific staff of Captain Beechey's expedition to this coast in 1827, made the following observations concerning it:

> To the north of Cape Thompson the coast runs out by means of a low spit to the distance of perhaps 20 miles into the sea. The low point itself seemed to be acquiring almost a daily accession to the basaltic gravel of which the beach was in greater part formed.[1]

The location of the Point Hope spit is undoubtedly due in large measure to the combined influence of the Kukpuk River and a coastwise current which sets northward out of Kotzebue Sound, at from one to three miles an hour. This current appears to be continuous with the current which sets northward through Bering Strait during the summer months. The current through Bering Strait forks a short distance north of the Strait, one branch bearing northwesterly along the Siberian coast, and the other "going north through Kotzebue Sound and thence along the mainland by Cape Seppings, Point Hope, and Icy Cape to Point Barrow at which point it goes off to the unknown northeast."[2]

The drift of the ice-beset "Jeannette" seems to be conclusive evidence of the northwesterly current to the west of the Strait.

The current through Bering Strait may, of course, be greatly accelerated or retarded by the winds, but they do not seem to be ever able to entirely check it. Captain F. W. Beechey recorded that he found a current in Bering Strait running against a heavy gale "at the rate of upward of a mile an hour in a N. 41° W. direction."[3]

The influence of this current is manifested as far south as Teller

[1] *Zoölogy of Captain Beechey's Voyage*, London, Bohm, 1839, p. 172.

[2] Chas. H. Stockton, *Natl. Geog. Mag.*, Vol. II, 1891, p. 183.

[3] *Narrative of a Voyage to the Pacific and Bering Strait*, Part II, 1831, p. 546.

on Seward Peninsula and it is reported to reach even as far to the eastward as Point Barrow. McClintock found a current setting eastward to the east of Point Barrow with a rate of 18 miles per day.[1] The depth of water affected by this current seems to be but a few feet. The writer observed evidence of this while aboard a schooner anchored off Cape Krusenstern in Kotzebue Sound during a calm. The waters of the sound swarm with various species of medusa and other plankton. From the rail of the anchored schooner these could be seen at and near the surface passing the vessel with a current of one and one-half or two miles an hour. A few feet below the surface, however—perhaps 10 or 12 feet—could be seen the same fauna almost or quite stationary. The shallow character of this northerly current in these waters was noted as early as 1826 by the careful observations of Captain F. W. Beechey who states concerning this current that "at the depth of nine feet its velocity was evidently diminished and at three and five fathoms there was none."[2] Captain Beechey observed also that the water of this current was much fresher than the deeper waters.

The writer has had abundant opportunity to note the influence of this current on coast deposits in the course of a 200-mile journey in a small boat along the coast of Seward Peninsula and near Cape Thompson. Almost every stream between the lagoon west of Teller and Cape Prince of Wales is deflected to the right by a bar on entering the sea. The long narrow bar at the mouth of Kanauguk River is a typical example of these bars. In the case of small creeks the bar may be only three or four yards wide, but when present it invariably turns the stream abruptly to the right as it is about to enter the sea. The tendency of the northerly current to deflect streams to the right is illustrated in Kotzebue Sound, by the bar at the mouth of the Inmachuk River. This bar has a length of about a third of a mile and extends nearly across the mouth of the valley occupied by the Inmachuk, forcing the river to enter the sound at the extreme east side of the valley. A small creek at Cape Thompson which is deflected abruptly to the right by a narrow bar is the nearest example to Point Hope of the influence of this current.

[1] Capt. McClintock, *A Narrative of the Discovery of the Fate of Sir John Franklin and His Company*, p. 72, 1868.

[2] *Op. cit.*, p. 578.

The relative position of shoals and coastal headlands likewise indicates the influence of the northerly current. An extensive shoal extends northward from Cape Prince of Wales for many miles with comparatively deep water south of the cape. At Point Hope a detached shoal with four and one-half feet of water over it lies to the north of the Point with deep water south of the Point. Cape Lisburne likewise has an outlying shoal with five fathoms of water over it, but it lies wholly to the north of the cape. At Point Barrow there is also a shoal lying wholly to the north of the Point.[1]

The bars cited, however, differ from the Point Hope spit in running parallel with the shore. Like them the Point Hope spit appears to have deflected the stream to the north, but unlike them it extends out nearly at right angles to the coast line. The considerable volume of the discharge of the Kukpuk River has no doubt been an important factor in neutralizing the tendency of the coastal current to turn the spit to the north.

In this connection tidal influence may also be considered. The tide, although small in the Arctic Ocean, is not a negligible element in considering the development of shore-line features. The mean range of the tides recorded for the northwest coast of Alaska and the adjacent parts of Siberia ranges from .2 of a foot[2] to $2\frac{1}{4}$ feet.[3] The tide at Point Hope is probably considerably less than two feet, but it is sufficient to give at the ebb a current to the southwest off the northwest shore of Point Hope.[4] This tidal-ebb current from the northeast would neutralize the tendency of the coast current to turn the point of the spit northward and the collision of the two currents would lead to the shore waste which they carried being dropped so as to build the point in a westerly direction. The cliffs forming the coast line at Cape Thompson have a northwest-southeast trend for six miles or more, giving the coast current its initial northwesterly or seaward trend. North of the Kukpuk River for nearly thirty-five miles the coast line of cliffs trends nearly north and south. This contrast in the trend of the coast on the north and the south sides of the point

[1] U. S. Hydrographic Office, Chart of the Bering Sea and the Arctic Ocean.

[2] Harris, *Eighth Intern. Cong. of Geog.* p. 399, 1905.

[3] DeLong, *Voyage of the "Jeannette,"* p. 890, 1883.

[4] Capt. F. W. Beechey, *op. cit.*, p. 577.

probably gives rise to a slight backset or eddy current to the southwest on the north shore of Point Hope, which may be an element in giving the spit its cuspate form.

In addition to the familiar marine agents, waves, tides, and currents, which are involved in shaping the shore-line features of all coasts, we have on the Arctic coasts a fourth agency which at times acts with far greater power and rapidity than either of the above-named influences. This is the Arctic ice-pack. The shallow character of all the navigable portion of the Arctic Ocean, north of Bering Strait which seldom exceeds 30 fathoms, affords peculiarly favorable conditions for the excavating and plowing activities of the ice-pack when grounded and under pressure. The nature of the difference between ordinary sea ice and the ice of the ice-pack is indicated in the following extract from Captain Hooper's "Ice Notes":

> The greatest thickness attained by direct freezing is about eighteen feet, at which thickness the increase by freezing at the bottom does not exceed the waste at the top by evaporation, which goes on slowly but surely at all times. The maximum thickness by direct freezing is generally reached the third winter. It is seldom that more than nine feet forms during one winter. The extraordinary thickness attained by the pack is due to accumulations of these naturally formed layers as they are forced one over the other by pressure due to currents of air and water. On account of the difficulties of ascertaining the thickness of the ice by measurement, the most reliable way appears to be by noting the depth of water at which it touches the bottom. This we found at Herald Island, Wrangle Island, and on the coast of Asia near Cape North to be about ten fathoms. In Bering Sea we made fast to ice grounded in six fathoms, and passed a number of detached pieces ground in eight fathoms.[1]

Osborn thus describes the ice encountered by McClure off the north coast of Alaska:

> Ice of stupendous thickness and in extensive floes, some seven or eight miles in extent, was seen on either hand; the surface of it is not flat, such as we see in Baffins Strait and the adjacent seas, but rugged with the accumulated snow, frost, and thaws of centuries.[2]

Captain McClintock, in passing around the north coast of Alaska, generally found the heavy ice aground in six or eight fathoms of water,

[1] Capt. C. L. Hooper, "Rept. of the Cruise of the U. S. Revenue Steamer 'Thos. Corwin' in the Arctic Ocean, 1881," *48th Cong. Ex. Doc., No. 204*, p. 128, 1884.

[2] McClure, *The Discovery of the Northwest Passage*, edited by Osborn, p. 83, 1857.

leaving a comparatively ice-free tract of water, three to six fathoms deep, between the ice-pack and the coast, through which he laid his course.[1]

All observers agree in ascribing great thickness to the ice of the Arctic ice-pack. The whalers distinguish it from the ordinary sea ice produced by one or two winters' freezing by calling it the "big ice."

Jarvis, in speaking of the ice-pack of the Alaskan coast, states that

though the pack contains no real icebergs it nevertheless extends six to eight fathoms below the water and occupies from a third to a half the depth of the shallow Arctic Sea.

Lieutenant Chas. H. Stockton, of the U. S. Navy, thus describes the action of this ice when it is driven ashore:

Sometimes a long line of heavy floe ice from the pack grounds in the shallow water near the shore during northerly winds, pressed from behind by the force and the weight of the entire northern pack. It is gradually forced up, plowing its way through the bottom, at the same time rising gradually along the ascent of the bottom toward the land.[2]

Lieutenant Stockton made a hydrographic survey of the anchorage near Point Barrow in which he

demonstrated that the contour of the bottom is constantly changed by the plowing and planing done by the heavy ice grounded and driven up by the pressure of the mighty ice-pack, under the influence of northerly winds and gales.[3]

In this connection the observations and opinion of Mr. A. J. Collier who has seen much of the Arctic coast of Alaska is of interest. He states that

Dr. E. O. Campbell, government school-teacher at Cape Chibukak, St. Lawrence Island, whose residence is nearly one-half mile back of the beach, reports that he has often feared the destruction of the mission buildings from the same cause (driving ashore of the ice-pack). The beach at Cape Chibukuk is marked by a series of regular ridges parallel to the shore, said by Dr. Campbell to have been pushed up by the ice-pack. In view of these considerations the barrier beaches of the shores of the Arctic Ocean and Bering Sea, though in nearly all respects they resemble the barrier beaches formed by wave and current action in southern altitudes, must in the opinion of the writer be regarded as in part due to material pushed up from the sea-floor by the ice-pack and only transported in a minor

[1] Osborn, *The Discovery of the Northwest Passage*, p. 71, 1857.

[2] Chas. H. Stockton, *Natl. Geog. Mag.*, Vol. II, 1891, pp. 182, 183.

[3] *Ibid.*, p. 182.

degree by wave action. Barrier beaches of this type are of common occurrence along the shores of the Arctic Ocean in Alaska from Cape Prince of Wales to McKenzie River.[1]

The preceding quotations seem to make plain the fact that the pack ice along the Arctic coast should be considered along with currents and waves as one of the most effective agencies concerned in the formation of shore-line features. When it is remembered that the navigable portion of the Arctic Sea northwest of Alaska shoals regularly from a maximum depth of about thirty fathoms toward nearly every part of the Alaskan coast, it will be seen that the conditions are peculiarly favorable for the grounded ice-pack to carry great quantities of submarine deposits to and toward the beaches. The reworking of these transported materials by wave action seldom leaves any permanent features which can be ascribed solely to ice action.

The Arctic ice-pack never retreats far to the north of Point Hope even in midsummer. The observations of Captain A. J. Henderson of the revenue cutter "Thetis" would indicate that it was probably not more than 100 miles to the north of Point Hope at any time during the past summer.

According to Dr. Driggs, the missionary at Point Hope, the ice-pack comes down from the north and closes on the spit before any very considerable amount of local ice has formed on the sea. This usually occurs late in October or in November. In 1908 the bulk of the ice-pack left the Point July 28. It usually leaves early in July. The period during which the Point is subject to wave and current action is therefore limited to about one-fourth of the year. It is probable, however, that the ice-pack is more effective during the other three-fourths of the year in moving submarine materials toward the spit than waves and currents would be.

Mr. Allen, a whaleman who has lived for several years on the Point Hope spit, told the writer that at times in the winter the ice-pack is forced against the south shore of the spit with a force that makes the entire spit tremble as from an earthquake. Joseph Tuckfield, another whaleman who formerly lived on the spit opposite the mouth of the Kukpuk River, was compelled to remove his house to an island in the

[1] A. J. Collier, "Geology and Coal Resources of the Cape Lisburne Region, Alaska," *U. S. G. S. Bull. No. 278*, p. 34, 1906.

inlet on account of the danger of the ice-pack over-riding the spit in winter.

It will readily be seen that a solid ice-pack six or eight fathoms in thickness, which would be of sufficient thickness to ground a little distance off the shore of the Point Hope spit, would be a most effective agent in ridging or piling up in front of it and shoving shorewards the unconsolidated gravels and sand at the bottom, under the influence of pressure from the south. Such a grounded ice-pack driven by the combined pressure of heavy south winds and the north-setting current as the pack starts north in summer undoubtedly plays an important rôle in the growth of the spit by shoving the sands and gravels of the bottom up within the limits of effective wave action. The pack no doubt acts similarly at times in bringing materials up on the northwest shore, but it has already been pointed out that at present destructive agencies are more effective on that side of the spit than are the combined constructive agencies.

EDITORIAL

With this number the *Journal of Geology* begins the publication of the Correlation Papers which were presented to Section E of the American Association for the Advancement of Science in Baltimore, in December, 1908. The first articles are those by President Van Hise and Professor Adams, and deal with the principles of pre-Cambrian geology. Later papers will deal with successive periods or groups of periods, and will appear in chronological order in successive numbers of the *Journal,* as follows: C. D. Walcott: "Evolution of Early Paleozoic Faunas in Relation to Their Environment;" A. W. Grabau: "Physical and Faunal Evolution of North America in the Late Ordovician, Silurian, and Devonian Time;" Stuart Weller: Correlation of Middle and Upper Devonian and Mississippian Faunas of North America;" G. H. Girty: "Physical and Faunal Changes of Pennsylvanian and Permian in North America;" David White: "The Upper Paleozoic Floras, Their Succession and Range;" S. W. Williston: "Environmental Relations of the Early Vertebrates;" T. W. Stanton: "Succession and Distribution of Later Mesozoic Invertebrate Faunas;" W. H. Dall: "Conditions Governing the Evolution and Distribution of Tertiary Faunas;" Ralph Arnold: "Environment of the Tertiary Faunas of the Pacific Coast;" F. H. Knowlton: "Succession and Range of Mesozoic and Tertiary Floras;" H. F. Osborn: "Environment and Relations of the Tertiary Mammalia;" Rollin D. Salisbury: "Physical Geography of the Pleistocene with Special Reference to Conditions Bearing on Correlation;" D. T. MacDougal: "Relation of Plants to Climate with Special Reference to Pleistocene Conditions;" T. C. Chamberlin: "Diastrophism as the Ultimate Basis of Correlation."

With these papers, several of Mr. Willis' maps of the North American continent, at various stages of its history, will be published, together with some explanatory notes. It is hoped that these articles will prove to be of general interest to readers of the *Journal,* as they were to those who heard them in Baltimore. It is possible that the several articles will be issued in book form, after the series is completed.

R. D. S.

Reviews

Stratigraphy and Paleontology of the Ordovician Rocks of Indiana. By E. R. Cumings. Thirty-second Annual Report of the Department of Geology and National Resources of Indiana, 1907, pp. 607–1188.

Professor Cumings has determined as accurately as possible the exact range and horizons of the different fossil species found by him in the Ordovician strata of southern Indiana and finds that the strata fall naturally into eight zones differentiated faunally as well as lithologically. Nickles in his earlier work used the bryozoa in determining the several divisions he proposed for these strata but Cumings, believing that the brachiopods are more generally suited especially for field determination, has used the latter as indicators. An important result of the present work is the discovery that in the Richmond beds the Saluda beds lie below, rather than above the Whitewater beds as believed by Foerste and others. The general absence of the later beds to the south is believed to indicate an extensive unconformity between the Richmond and the overlying Clinton. The major part of the paper is taken up with redescriptions of the fossils mainly drawn from the original descriptions.

The careful stratigraphic work is a credit to Professor Cumings and an advance in the right direction.

J C. J.

The Geology of the Gold Fields of British Guiana. By J. B. Harrison, Director of the Department of Science and Agriculture and Government Geologist. With Historical, Geographical, and other chapters by Frank Fowler and C. Wilgress Anderson.

Since 1884, when gold mining on an important scale was first undertaken, British Guiana has produced about $35,000,000 gold, most of which has been recovered from placer and residual deposits. The gold-bearing area is said to cover more than 1,000 square miles. The country is heavily forested and the rocks are exposed mainly along the streams and in ravines where torrential rains have cut through the deep residuum.

The oldest rocks are crystalline schists, probably of pre-Cambrian age, which vary in character from granitic gneiss to very basic schist. This

series is intruded by a great variety of porphyritic rocks and is overlaid by sandstones and conglomerates forming a series from 2,000 to 3,000 feet thick, which is in the main flat lying and is not greatly deformed. This group of rocks is not known to contain fossils, but its relationship to rocks of known age is said to have been made out in Venezuela where it is regarded as Cretaceous. The schists and the sandstones are intruded by diabase which the author regards as a source of much of the gold. The relatively fresh rock carries from a trace to 17 grains per ton.

Owing to the humid climate and tropical vegetation the rocks have weathered to great depth. Laterite, the residual product of the basic rocks, is known to be as much as 100 feet deep in some places. In the laterite there is a marked concentration of iron and clay and locally of gold, which it carries in amounts varying from traces to 15 pennyweights per ton. The laterite also contains irregular masses of rich quartzose ore which is presumably altered vein-stuff, but such masses are not abundant and the conclusion is that not more than 10 per cent. of the placers have originated from quartzose ores. The principal source is regarded as the basic igneous rocks in which, through decomposition to laterite, there has been a marked concentration *in situ*. Further concentration has taken place in some of the stream gravels. From the descriptions given, the laterite areas seem to offer attractive fields for prospecting for large low-grade gold deposits which should be very economically worked.

W. H. E.

The World's Gold. By L. De Launay, with an Introduction by C. A. Conant. Translated by Orlando Cyprian Williams. New York and London: G. P. Putnam's Sons.

This work is arranged for the banker and economist, rather than the geologist and metallurgist. The geographic distribution and the extraction of gold are treated in an interesting and readable manner, but the future production of gold is obviously the subject which is of greatest importance. Statistics are given which show that the gold production of the world has steadily increased since the Boer war, reaching over four hundred million dollars in 1906. The writer concludes that the next fifteen years will probably be marked by a great production of gold, which will afterward decline. He concludes, however, that the supply will be adequate for the purposes required, owing to a more general use of instruments of credit.

W. H. E.

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EVOLUTION OF EARLY PALEOZOIC FAUNAS IN RELATION TO THEIR ENVIRONMENT[1]

CHARLES D. WALCOTT

III

CONTENTS

INTRODUCTION

The evolution of early Paleozoic faunas could be treated with far greater effectiveness if the studies now in progress on the Cambrian faunas were nearer completion. That of the brachiopods is well advanced[2] but the great collections of the U. S. National Museum, representing the crustacea and other invertebrates, have not been studied as to their mode of occurrence, geographic distribution, and biologic and environmental relations. Only a brief summary of the known evidence afforded by the Cambrian rocks and faunas of North America is considered in this paper.

Animals and plants, as now known, are profoundly influenced by

[1] Read before Section E of the American Association for the Advancement of Science, Baltimore meeting, December, 1908.

[2] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 4, 1908, pp. 139–65.

their environment, hence we will first broadly outline the conditions under which the known marine organisms of Cambrian time lived.[1]

NORTH AMERICAN CONTINENT AT THE BEGINNING AND AT THE CLOSE OF CAMBRIAN TIME

The information obtained since the publication of my first map on this subject in 1891[2] has been assembled on the two accompanying maps by Mr. Bailey Willis. The first map outlines a central mass of pre-Cambrian land, flanked on either side by large barrier islands that served to protect straits, sounds, or seas from the open ocean. Ocean currents flowed through the sounds with varying force and volume, not only from the cold arctic waters to the north, but from the warm tropical region to the south. The relative position of land and sea is based on the present interpretation of the observed characters and distribution of the pre-Cambrian and Lower Cambrian rocks. The distribution of Lower Cambrian faunas indicates the probable courses of the marine currents. A fundamental assumption is that the great ocean basins and continental masses occupied their present relative positions during at least the Algonkian portion of pre-Cambrian time.

The map of the continent at the close of Cambrian time shows that during this period upon the continental area marked changes in the positions of the land and sea took place. Broad shallow seas followed the transgressing shore-line of Middle Cambrian time, offering most favorable conditions for the long-continued development and distribution of marine life.[3] There were undoubtedly deep and shallow seas and bays, cold and warm waters, strong and weak ocean currents of unlike temperatures, protected bays with sandy and muddy bottoms, shore lines gently sloping to deep water, and many conditions promoting the evolution of the faunas through favorable or unfavorable changes in environment, temperature, and food-supply.

The sediments of Cambrian time are mainly those deposited near the shore-line and in adjacent relatively shallow waters. There is little if anything to indicate deposits of the abyssal sea. If the littoral

[1] *Bull. Geol. Soc. Amer.*, Vol. X, 1899, pp. 199–244.

[2] *Bull. U. S. Geol. Survey*, No. 81, 1891, Pl. III.

[3] See theoretic section at the close of Cambrian time: *Bull. U. S. Geol. Survey*, No. 81, 1891, Pl. II.

fauna of the Cambrian sea had begun to work its way down the continental slopes beyond the continental margin into the depths, we can find no evidence of it, either in the Cambrian rocks, or in the character of the present deep-sea fauna.

The life of Lower Cambrian time included Crustaceans (trilobites, ostracods), Mollusca (gasteropods), Molluscoidea (brachiopods), Vermes (annelids), Echinodermata (cystoids), Coelenterata (sponges, corals, jelly-fishes), and the simplest animals, the Protozoa (rhizopods). Immense quantities of microscopic, unicellular plants were undoubtedly present, and, together with the minute Protozoa, must have formed the primary food-supply.[1]

The rôle assigned by Dr. W. K. Brooks to microscopic forms was an important factor in Cambrian time, for the organisms found in the rocks of that period were mainly carnivorous, and were adapted either to straining minute organisms from the water, or to gathering them up from the bottom.

Uniform marine physical conditions over the submerged portions of the continental platform in Lower Cambrian time are indicated by the uniformity of the fauna on opposite sides of the present continent. Whether this fauna was distributed between the east and the west to the north of the central land-area, or south of it, is not definitely determined, yet the absence of Lower Cambrian rocks and fossils from the collections made in the Arctic region, and the presence of closely allied species in the Lower Cambrian rocks of Alabama and California, point to the southern coast-line as the probable highway for the distribution of the littoral fauna. Nothing that suggests the Lower Cambrian fauna is known from South America; in this case, deep water may have been the barrier.

With the advent of Middle Cambrian time land-areas came into existence on the northeast, forming barriers which so affected marine conditions in relation to life that the Paradoxides fauna developed in the Atlantic basin and the Olenoides fauna in the Appalachian region south of the Champlain Valley. To the south and on all sides of the

[1] W. K. Brooks, *Studies from the Biological Laboratory, Johns Hopkins University*, Vol. V, 1893, pp. 136–38. On p. 137 Dr. Brooks says: "The simplicity and abundance of the microscopic forms and their importance in the economy of nature show that the organic world has gradually shaped itself around and has been controlled by them."

central land-area the advancing seas forced the faunas to shift their habitat and either to adjust themselves to the new conditions or to perish. Local isolation for long periods led to the development of new forms, and these, when the barriers were removed, contested and competed for their position and life with other faunas until, by a process of elimination of those least fit to survive, there was hastened the development of a large and varied fauna. With the close of Middle Cambrian time more stable conditions returned, and the era of rapid evolution was checked until the impulse of new conditions of environment and an accumulated tendency to change resulted in the great evolution of life in the lower Ordovician.

LIFE AT THE BEGINNING OF KNOWN CAMBRIAN TIME

The traces of pre-Cambrian life, though very meager, are sufficient to indicate that the development of life was well advanced long before Cambrian time began. The characteristic fossil of the known pre-Cambrian fauna is *Beltina danai*,[1] a crustacean probably more highly organized than the trilobite. The associated annelid trails indicate that this phase of the fauna was also strongly developed. Stratigraphically, this fragment of what must have been a large fauna occurs over 9,000 feet beneath an unconformity at the base of the upper portion of the Lower Cambrian in northern Montana.[2] This fact indicates that it is practically hopeless to search for the first forms of life—those that could leave a trace of their existence—in strata now referred to the Cambrian or early Paleozoic. With this thought in mind we shall consider what is known of the life of early Lower Cambrian (Georgian) time.

The oldest known Cambrian fossils are found deep down in the Lower Cambrian strata of southwestern Nevada and the adjoining Inyo County area of eastern California. In sections 120 miles apart the Lower Cambrian has a thickness of over 5,000 feet, with a great limestone forming the upper 700 to 2,000 feet. Below this limestone calcareous strata occur, but the predominating rocks are sandstones, and arenaceous, siliceous, and calcareous shales. In the lower 400

[1] *Bull. Geol. Soc. Amer.*, Vol. X, 1899, pp. 238, 239.

[2] C. D. Walcott, *Observations of 1908*.

feet of the Waucoba Springs section and the Barrel Spring section south of Silver Peak in western Nevada[1] the fauna includes:

Annelid trails
Protopharetra, sp. undt.
Archaeocyathus, sp. undt.
Ethmophyllum cf. *whitneyi* Meek[2]
Mickwitzia occidens Walcott[3]
Trematobolus excelsis Walcott[4]
Obolella, sp. undt.
Orthotheca, sp. undt.
Holmia rowei, new species
Holmia weeksi, new species

Although this fauna, according to our present knowledge, is the oldest known Cambrian fauna, it includes representatives of the several classes of invertebrates which I will enumerate.

Actinozoa.—The corals are represented by a very primitive form of *Protopharetra*, a small form of cup-shaped *Archaeocyathus*, and a small *Ethmophyllum* closely allied if not identical with *Ethmophyllum whitneyi* (Meek),[5] which occurs higher in the section. The latter is not a notably simple or primitive form of the Archaeocyathinae; on the contrary, it is nearly as far advanced as any species known in the Cambrian.

Vermes.—The annelid borings and trails that occur in and on the sandstones and shales are much like those of the Middle and Upper Cambrian.

Molluscoidea.—The two species of brachiopods represent widely separated genera. *Mickwitzia occidens* Walcott[6] is one of the primitive forms of the Paterinidae, while *Trematobolus excelsis* Walcott[7] is a typical form of the Siphonotretidae. The interval represented by the relative development of *Mickwitzia* and *Trematobolus* is sufficient to convince us that we must look far back in Cambrian, or it may be pre-Cambrian, time for the progenitors of the inarticulate brachiopods.

[1] Walcott, *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 5, 1908, pp. 185–89.

[2] See *Bull. U. S. Geol. Survey*, No. 30, 1886, pp. 81–84.

[3] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 3, 1908, p. 143.

[4] *Ibid.*, p. 146.

[5] *E. gracile* is considered to be a synonym of *E. whitneyi* (*Bull. U. S. Geol. Survey*, No. 30, 1886, pp. 81–84).

[6] *Smithsonian Miscellaneous Collections*, Vol. LIII, No. 3, 1908, p. 143.

[7] *Ibid.*, p. 146.

Pteropoda.—The forms representing *Orthotheca* are abundant, large, strong, and evidently as well developed as those of the Middle Cambrian.

Crustaceans.—The trilobites thus far found at this horizon are confined to two species of the genus *Holmia*. One of them, *Holmia weeksi*, new species, has many segments, and is more primitive than such forms as *Olenellus thompsoni* Hall[1] and *Holmia bröggeri* (Walcott)[2] of the upper portions of the Lower Cambrian section. The other species, *Holmia rowei*, new species, is of the same general type as *Holmia bröggeri*. The absence of all other trilobite genera is the most marked feature of this early Cambrian fauna.

In the section 100 miles to the south, at Resting Springs, Inyo County, California, a brachiopod closely related to *Billingsella highlandensis* Walcott[3] occurs 2,800 feet below the upper limestone, in association with the trilobite *Holmia rowei*.

Comparing the species in the early Lower Cambrian fauna with the Olenellus fauna, in strata 5,000 feet higher in the section, we find a marked advance in the variety of the later fauna, but we do not know how much of this may be due to the absence, from our collections, of genera and species that may have existed during the deposition of the earlier sediments. In the earlier fauna of the Waucoba section the class characters of the Arthropoda, Mollusca, Molluscoidea, Vermes, and Coelenterata were developed, and while the study of the genera and species adds a little more to our knowledge of the rate of convergence backward in geologic time of the lines representing the evolution of animal life, it, at the same time, proves that a very long time-interval elapsed between the beginnings of life and the epoch represented by the Olenellus fauna.[4]

DISTRIBUTION OF THE LOWER CAMBRIAN (OLENELLUS) FAUNA OVER THE NORTH AMERICAN CONTINENTAL PLATFORM OF CAMBRIAN TIME

The Olenellus fauna lived on the eastern and western sides of a continent that rudely outlined, in its general configuration, the North

[1] See *Bull. U. S. Geol. Survey*, No. 30, 1886, p. 167.

[2] See *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 638.

[3] *Proc. U. S. National Museum*, Vol. XXVIII, 1905, p. 237.

[4] *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 595.

American continent of today. Strictly speaking the fauna did not live upon the outer shore facing the ocean, but on the shores of interior seas, sounds, straits, or lagoons that occupied the intervals between the several land-masses that rose from the partly submerged continental platform east and west of the central continental area. On the eastern side, the first land east of the central portion of the continent extended from Alabama northeast along the line of the present Appalachian range to and including the Green Mountains of Vermont. Whether or not the fauna existed in the Connecticut River region to the east of the Green Mountains is unknown. That it occurred further east is shown by its presence in eastern Massachusetts and northwestern Newfoundland. Its presence in a still more easterly basin is proved by its occurrence on the peninsula of Avalon, to the east of the area of Archean rocks crossing central Newfoundland.

It is not my intention to discuss the evidence upon which the assertion of the presence of these various outlying seas, sounds, etc., is based. The evidence of the existence of such bodies of water has been well presented by Dana.[1] What I wish to call attention to now is that the Olenellus fauna lived upon the eastern and western sides of the main North American continental area of late Algonkian and early Cambrian time. This view is sustained by the following observations: (1) The strata containing the Olenellus fauna are known only in the eastern and western portions of the continent; (2) as far as known the Lower Cambrian strata are absent in the interior of the continent; (3) the Upper Cambrian strata are unconformably superjacent to the Algonkian and Archean rocks over the areas where the Middle and Lower Cambrian formations are absent; (4) the strata of the Middle and Lower Cambrian are comformably beneath the Upper Cambrian on the eastern and western sides of the present continent in all sections where the three divisions are present.[2]

The oldest known portion of the Olenellus fauna is limited to that

[1] "Areas of Continental Progress in North America, and the Influence of the Conditions of These Areas on the Work Carried Forward within Them." *Bull. Geol. Soc. Amer.*, Vol. I, 1889, pp. 36–48. "Archean Axes of Eastern North America," *Am. Jour. Sci.*, 3d ser., Vol. XXXIX, 1890, pp. 378–83.

[2] The matter contained in the two preceding paragraphs appeared under the heading "Habitat of the Olenellus Fauna" in the *Tenth Annual Report, U. S. Geol. Survey*, 1891, pp. 556, 557.

section of the Cordilleran area mentioned on p. 197. This fauna was undoubtedly present on the continental shelves to the north and south, and may have been distributed around the southern extremity of the central land-area to the Hudson and Champlain valley region. Future investigation may thus prove that the *Holmia asaphoides* fauna[1] of eastern New York is the oldest part of the Olenellus fauna upon the eastern side of the continent, and that it may be compared with the *Holmia rowei* fauna of the Cordilleran area. The presence in both localities of genera belonging to the Archaeocyathinae indicates that warm currents were passing through the straits or sounds to the east and west of the central continental areas, and that conditions were favorable for a varied fauna. The arenaceous beds (with ripple-marks and trails) of the western Nevada-California area and the interformational conglomerates of eastern New York prove the presence in both areas of relatively shallow water.

The *Olenellus thompsoni* fauna,[2] of late Lower Cambrian time, is widely distributed about the margins of the continental area. Beginning at the Straits of Belle Isle on the northeast, it has been found in eastern Massachusetts, western Vermont, eastern New York, eastern Pennsylvania, and along the Appalachian area as far south as central Alabama. In the Cordilleran area it is known to extend from Inyo County, California, to the Wasatch Mountains of Utah, and northward to the line of the Canadian Pacific Railway in British Columbia.

With the exception of vertebrates, echinoderms, and cephalopods, the class-characters of the early Lower Cambrian fauna of Nevada were well advanced toward the varied and rich fauna of the lower Ordovician.

CONDITIONS DURING MIDDLE AND UPPER CAMBRIAN TIME

The physical conditions of the late Lower Cambrian time continued into early Middle Cambrian time, followed during Middle Cambrian time by a gradual submergence through erosion and probable warping of the surface of most of the continental area south of the Great Lake region.[3] As the marine waters slowly encroached upon this great area and upon the shores adjoining the Appalachian and Cordilleran

[1] *Tenth Annual Report, U. S. Geol. Survey*, 1891, p. 570.

[2] *Ibid.*, p. 569.

[3] *Am. Jour. Sci.*, Vol. XLIV, 1892, pp. 56, 57.

seas the marine life of the times met with conditions favorable to a large development. This is illustrated by the abundant and varied Paradoxides fauna on the Atlantic side and the equally varied Pacific basin Olenoides[1] fauna found in nearly all localities where the Middle Cambrian sediments were deposited.

EVOLUTION OF FAUNAS

That the environment of the faunas of Middle Cambrian time was more favorable for their rapid evolution than that of Lower and Upper Cambrian time is strikingly shown by the stratigraphic distribution of the brachiopods. In the restricted waters of Lower Cambrian time the known brachiopods (of the entire world) were represented by 20 genera and 75 species. In the expanding seas of Middle Cambrian time 31 genera and 243 species are known to have existed. With the more uniform conditions of Upper Cambrian time, and the dying-out of the impulse to variation created by both favorable and unfavorable environments in Middle Cambrian time, the brachiopods decreased in variety and numbers, and are represented by only 23 genera and 137 species.

About the same relative numerical ratios are exhibited by the trilobites but the exact statistics are not yet available. The favorable environment of the Middle Cambrian fauna is well illustrated by the development of *Ogygopsis*, *Asaphiscus*, and *Bathyuriscus* of Cordilleran Middle Cambrian time,[2] genera which are so far in advance of contemporary trilobitic genera that they have sometimes been referred, upon biological grounds, to the Upper Cambrian.[3]

The closing of Cambrian time was accompanied and followed by changes in the relations of the sea and land upon the continental platform that were favorable, like those of Middle Cambrian time, to the

[1] The Olenoides fauna is found on both the eastern and western sides of the northern Pacific Ocean, and the Paradoxides fauna on both sides of the northern Atlantic Ocean. This fauna includes a group of trilobites that are represented more or less fully in the Middle Cambrian rocks of North America, east of the Atlantic basin Paradoxides faunas, and in eastern Asia. The fauna includes: *Olenoides* Meek, *Dorypyge* Dames, *Neolenus* Matthew, *Dorypygella* Walcott, *Damesella* Walcott, *Blackwelderia* Walcott, *Zacanthoides* Walcott, and *Kootenia* Walcott.

[2] See *Bull. U. S. Geol. Survey*, No. 30, 1886, Pls. XXX, XXXI, and *Canadian Alpine Journal*, Vol. I, No. 2, 1908, Pl. 3.

[3] G. F. Matthew, *Trans. Roy. Soc., Canada*, 2d ser., Vol. V, 1899, p. 64.

evolution of new genera and species, and to the existence of multitudes of individuals of the prolific species.

This is not the place for a detailed discussion of the faunas and sediments of the lower Paleozoic. Only the broadest generalizations can be touched upon. I think, however, that sufficient has been said to fix in your minds the following conclusions: (1) That more or less uniform and favorable, even warm, climatic conditions must be appealed to in explanation of the widespread occurrence of almost identical coral-like organisms in the Lower Cambrian, and of the vast number of individuals of various species of trilobites, etc., which existed in Middle Cambrian time; (2) that the rapid and accentuated development of the Middle Cambrian faunas was due in great measure to enlarged opportunity caused by the extension of the Cambrian seas and the consequent shifting of shore-lines and changes in habitat, etc.; (3) that the diversification of the Middle Cambrian fauna, as a whole, may have been due, in a large degree, to the rapid development of narrowly provincial or isolated faunas that were subsequently merged into the more widely distributed fauna by the breaking-down of the restrictive barriers; and (4) that a free and more or less complete interchange of currents in the Cambrian seas was strongly instrumental in producing those cosmopolitan faunas so characteristic of the early Paleozoic. In other words it is evident that the evolution of the early Paleozoic faunas was profoundly influenced by their environment.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

At the Baltimore Meeting of the American Association for the Advancement of Science a number of paleogeographic maps of North America, representing the continent at intervals from Cambrian to Quaternary, were exhibited. They had been prepared in collaboration with some of the geologists who presented papers in the symposium on correlation, and to a certain extent they serve to illustrate the changing geologic conditions which form a factor in the problems of correlation. I have been requested to publish them in connection with the correlation papers in the *Journal of Geology*, and am glad to do so, although it is not practicable to present a discussion of the particular facts which have been considered in the construction of each individual map.

In general the lines of evidence have been considered somewhat in the following manner.

A certain period having been selected as that which should be mapped, the epicontinental strata pertaining to that time interval have been delineated. The phenomena of sedimentation and erosion have then been correlated, with a view to determining the sources of sediment and topographic conditions of land areas, and from these data the probable positions of lands have been more or less definitely inferred. Thus, certain areas within the continental margin are distinguished as land or sea, and these areas may be defined as separate bodies or connected according to inferences based upon isolated occurrences or upon later effects of erosion.

It is assumed that the great oceanic basins and such deeps as the Gulf of Mexico and the Caribbean have been permanent features of the earth's surface at least since some time in the pre-Cambrian. These deeps can thus be placed upon the map and their connection with the epicontinental seas may be tentatively established.

When the distribution of lands and waters is thus inferentially

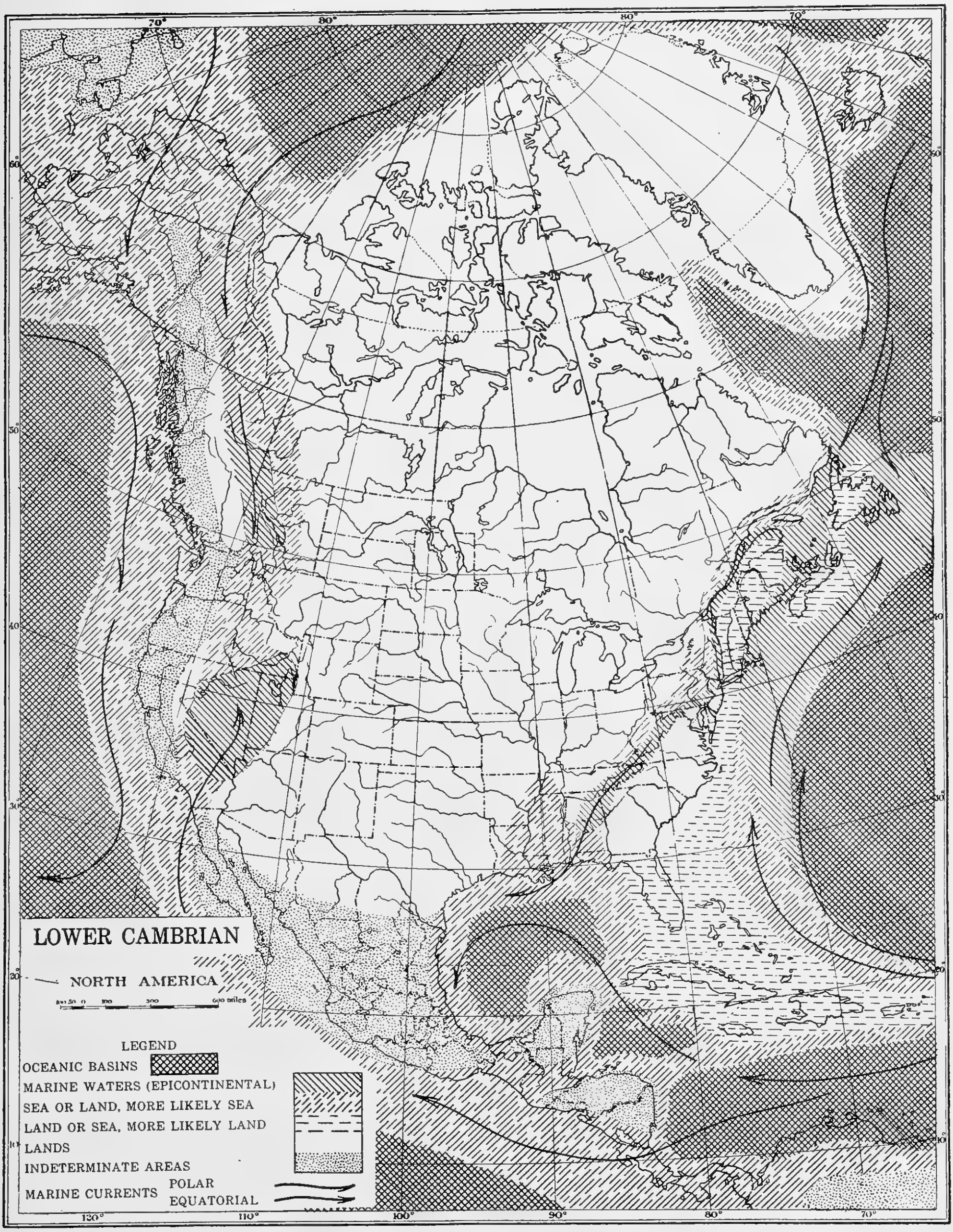
[1] Published by permission of the Director of the U. S. Geological Survey.

completed, we may infer further that the dominant features of oceanic circulation have obeyed the conditions of atmospheric circulation and of rotation of the sphere which now govern the great oceanic eddies. We may introduce in the Atlantic and Pacific the dominant drifts from east to west in equatorial regions with the resulting circulation northward along the east coast and southward along the west coast of the continent. A circulation of the oceanic waters in the epicontinental seas must result from the great oceanic drifts, and the direction of flow will be determined by the configuration of the lands and the depths of the seas.

From the geographic conditions thus developed inferences regarding the climate and the life habitats of the time may be drawn. If now we turn to the records of paleontology and compare the distribution of faunas and floras with the conditions of distribution which should result from the inferred physical phenomena, we may check the whole line of reasoning and by a readjustment draw a step nearer to the truth. This is the method which has been pursued in making the maps of North America that are published with the papers in this number and that will appear in connection with further papers of the series.

In a first essay of this kind (and I am not aware of any earlier attempt to combine the various lines of evidence in a similar manner) it is probable that important facts have been overlooked. The very broad scope of the discussion makes this probability almost a certainty, and it is not to be expected that the maps here presented should give a final or satisfactory solution of the problems. They are to be regarded as tentative and suggestive only.

On one point they have been particularly criticized, it being said that each individual map covers so long a period of time and such diverse conditions that they do not truly represent any special geographic phase of the continent. This criticism is valid, and one of the steps in the advancement of knowledge will be that of selecting narrower time limits and more precise correlations than have been attempted in these cases. We may undoubtedly make progress in this direction at the present time so that the fifteen maps which will accompany this series may be replaced by two or three times as many; but there is danger in carrying the refinements too far on the


LOWER CAMBRIAN
NORTH AMERICA
600 miles
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
130°
110°
100°
90°
80°
70°

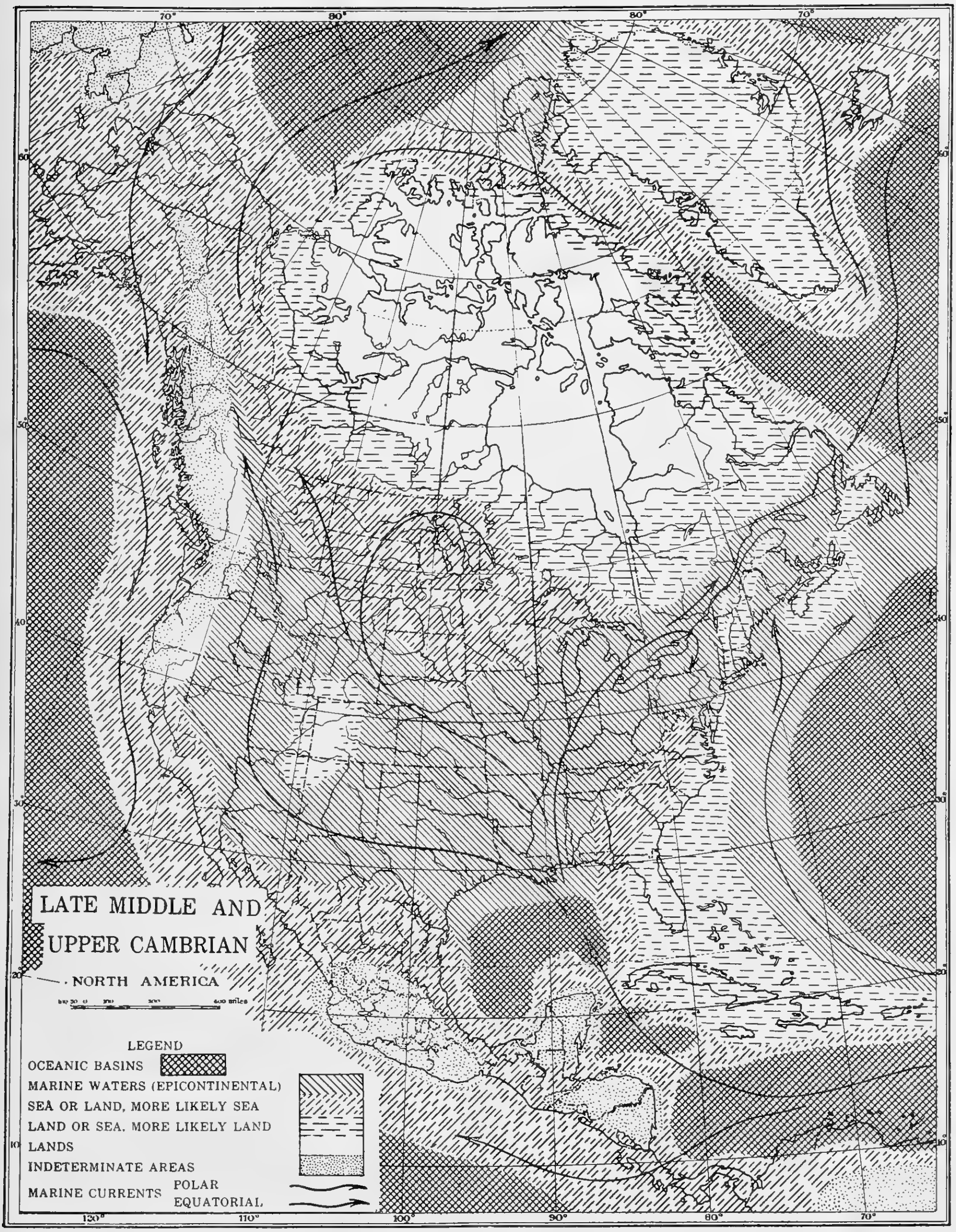
basis of paleontologic correlation alone, since it is still difficult to distinguish between synchronous and homotaxial faunas or floras. It may be hoped that these paleogeographic studies will themselves assist us to a better understanding of the evolution of life conditions and thus lead to a solution of some of the problems of correlation with the aid of biologic evidence.

1. LOWER CAMBRIAN NORTH AMERICA

The map of lower Cambrian North America presented herewith conforms to the outline developed by Mr. Walcott in the course of his studies. East and west of the central land mass are relatively narrow sounds limited on the oceanic side by islands or land masses of indeterminate extent. The old land area of Appalachia is believed to have covered the region of the West Indian Islands, it being well established that a somewhat extensive land extended to the southeast of the Appalachian trough, and it being plausible that that land lay between the Atlantic deep on the northeast and the deeps of the Caribbean and Gulf of Mexico. In the adaptation of marine currents to oceanic and continental features, it is inferred that the return waters from the Arctic occupied the sounds along the inner continental margins. The distribution of these currents suggests that the habitat of the lower Cambrian fauna of the Appalachian trough on the east and the British Columbia-Nevada trough on the west was determined by the cool waters flowing southward. This view of dispersion of the faunas from the north is not shared by Mr. Walcott, who presents the alternative hypothesis of a connection of the faunas around the southern margin of the continent. The fauna of the Nevada basin appears to belong to warmer waters than that of British Columbia, inasmuch as it contains corals. The land areas of lower Cambrian time throughout the northern hemisphere appear to have been large. There is evidence in the character of the sediments and in glacial deposits in China that there were marked contrasts of climate.

2. LATE MIDDLE AND UPPER CAMBRIAN NORTH AMERICA

The map of late middle and upper Cambrian North America represents an expansion of the area of the epicontinental sea which probably was not at any time actually reached. The middle Cam-


LATE MIDDLE AND
UPPER CAMBRIAN
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110°
100°
90°
80°
70°

brian sea extended further in certain areas than the upper Cambrian and retreated while the upper Cambrian sea spread over other regions. These details are not well worked out, though in part recognized. The map truly presents, however, the general fact that North America was to a great extent submerged and the land areas very markedly reduced. The prevailingly fine and calcareous sediments of the wide seas and the siliceous coastal plain sediments of the littoral deposits indicate that the relief of the land was low.

The conditions of marine circulation had apparently been modified by the expansion of the interior sea, and the climate conditions incident to widespread seas and low lands had become so ameliorated that similar habitats prevailed throughout a very wide range of latitude.

PHYSICAL AND FAUNAL EVOLUTION OF NORTH AMERICA DURING ORDOVICIC, SILURIC, AND EARLY DEVONIC TIME

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IV

The following classification of the Ordovicic[1] and Siluric has recently been published by the author and will be made the basis of the present discussion of these systems:[2]

F. Upper Siluric or *Monroan.*
E. Middle Siluric or *Salinan.*
D. Lower Siluric or *Niagaran.*
C. Upper Ordovicic or *Trentonian.*
B. Middle Ordovicic or *Chazyan.*
A. Lower Ordovicic or *Beekmantownian.*

A. THE LOWER ORDOVICIC OR BEEKMANTOWNIAN

At the beginning of Ordovicic time, as now generally recognized, the great marine transgression or positive diastrophic movement, which obtained throughout Upper Cambric time, was in progress, so that the early Beekmantown strata overlapped the Upper Cambric (Saratogan) and came to rest directly upon the crystalline basement. The basal portion of the sedimentary series is generally quartz sandstone of greater or less purity, or sometimes a conglomerate with crystalline pebbles of local origin. This basal sandstone is commonly referred to the "Potsdam," that term being used synonymously with Upper Cambric. Aside from the question as to whether or not the Potsdam sandstone of the type locality is really of Upper Cambric age, it must of course be apparent that in a normally overlapping series of strata deposited by a transgressing sea, the basal sand member would naturally rise in the series in the direction of transgression and overlap, and that hence a basal sand is not everywhere of the same age. In northwestern New York, in Ontario, and in northern Michigan, these basal sands are probably in all cases

[1] This journal does not approve the terms "Ordovicic," "Siluric," etc.

[2] *Science*, N. S., Vol. XXIX, pp. 351–56, February, 1909.

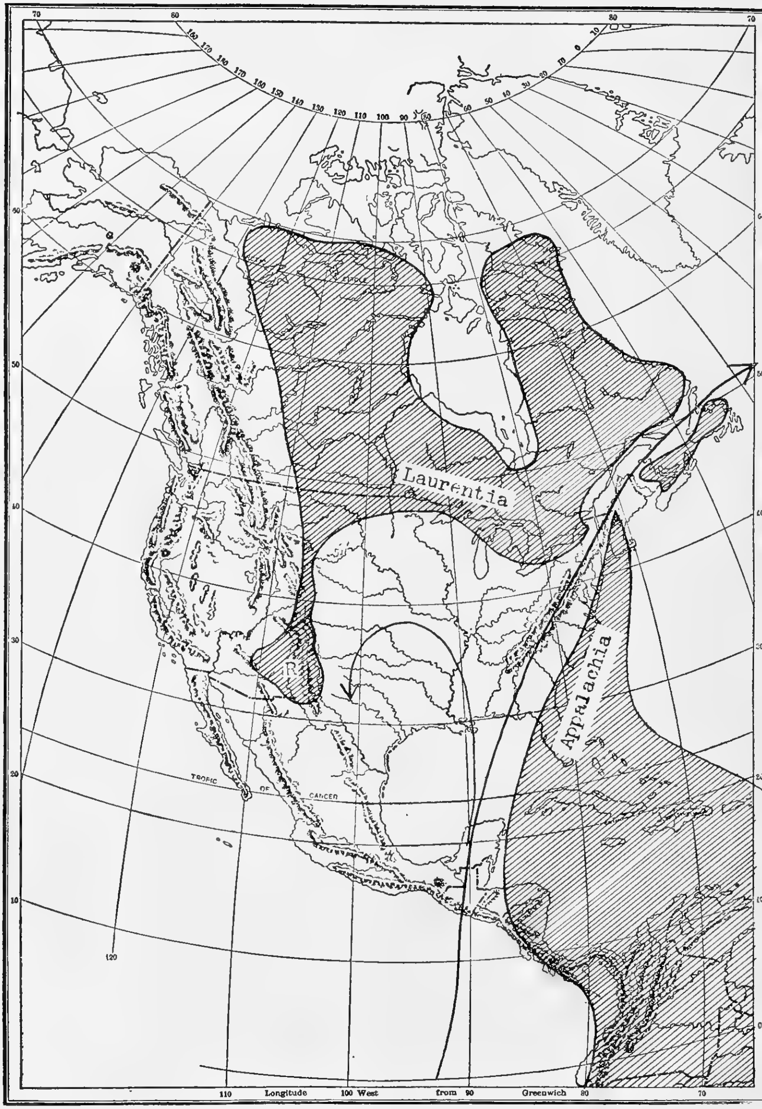


Fig. 1.—Paleogeographic map of North America at end of Upper Cambric time, and probable currents. R. Peninsula of Rockymontana.

post-Saratogan, belonging to the basal portion of the Beekmantown series as generally defined. This is clearly true of the conglomeritic layer at the base of the Little Falls dolomite in the Mohawk Valley, and is probably also true of the so-called Potsdam of the Black River region and the westward continuation of the outcrop in Canada. There is good reason for believing that the sea at the end of Saratogan time did not cover the present site of Lake Ontario, and that the basal sandstones of the Ontario region belong to the base of the overlapping early Beekmantown. In some cases the basal sands (St. Mary's sands) are even younger than this (Lowville, N. Y., Encampment d'Ours, Isle Lacloche, etc.), for the immediately overlying strata carry late Chazy (Lowville) or even Black River fossils, and, so far as now known, there is no break in sedimentation between these basal sands and the beds immediately succeeding, which thus determine their age. In all such cases, until positive evidence of a pronounced physical break or disconformity is determined between the two series, or until the basal bed is shown by unquestionable fossil evidence (exclusive of Scolithus, burrows, trails, and other problematic markings which may characterize various Paleozoic sandstones) to be of Cambric age, logical reasoning compels us to regard the age of the basal sandstone in each case as essentially that of the fossiliferous beds immediately succeeding, unless these are the very lowest post-Cambric beds.

One other point should be clearly emphasized. It is by no means established that the basal sandstones are everywhere of marine origin. In fact, the general absence of fossils, the frequent cross-bedding and other characters point rather to a continental origin of a part, at least, of this basal series, the agents of deposition being rivers or the wind. There is scarcely a geologist today who is satisfied with the complacent explanation, current only a short time ago, that the absence of fossils in a sandstone is due to "unfavorable conditions at the time of deposition," or to subsequent destruction of the fossils, in some mysterious way or other. That fossils abound in marine sandstones of all kinds, and even in conglomerates, is a well-known fact, and that the sands along our modern sea-shores are rich in shells and other hard parts of organisms, is equally a matter of common knowledge. The argument that the absence of fossils in a

rock which elsewhere carries them, indicates some peculiarity of the sea-shore at that point, capable of barring the life of the sea, is a laborious explanation to fit a preconceived notion of the origin of the formation in question. Nor must we forget that the North American continent was above the sea during long periods of pre-Cambric and Cambric time, and that on those vast land areas subaërial deposition as well as erosion must have been in progress. It is therefore to be expected that in many, if not in most, regions the Paleozoic series begins with a formation of continental origin, the upper portion of which was reworked by the transgressing sea, and became incorporated as a basal member of the marine series succeeding. In this manner the contact between the continental and marine series often became an apparently conformable and perfectly gradational one, the hiatus between them being masked. It will of course be impossible in such a case to determine whether a basal bed of continental origin is of pre-Cambric, of Cambric, or of post-Cambric age; all that can be determined is the period at which its upper portion was reworked by the transgressing sea. If the basal bed is of slight thickness it is in such a case best referred to the age of the immediately succeeding marine formation.

The question naturally arises, should the lower portion of the Beekmantown be referred to the Cambric with which it forms a continuous transgressive series, or should it be retained in the Ordovicic with the remainder of the Beekmantown? While in New York the fauna is, so far as known, an Ordovicic one, in other localities beds considered of the same age carry a mixed Cambric and Ordovicic fauna. In this respect these beds and the typical Saratogan, as well as the St. Croix series of Minnesota and Wisconsin, probably correspond to the Tremadocien of Europe, which is classed as Upper Cambric by British geologists, but by German and other continental geologists as basal Ordovicic (Unter Silur). Matthew correlates these beds with the *Asaphellus homfrayi* beds of the St. John section, and so places them above the *Dictyonema flabelliforme* beds, which at present are also included in the base of the Ordovicic by some continental geologists. That such transitional formations are to be expected in any complete depositional series is, of course, obvious, and their precise reference is a matter of secondary importance.

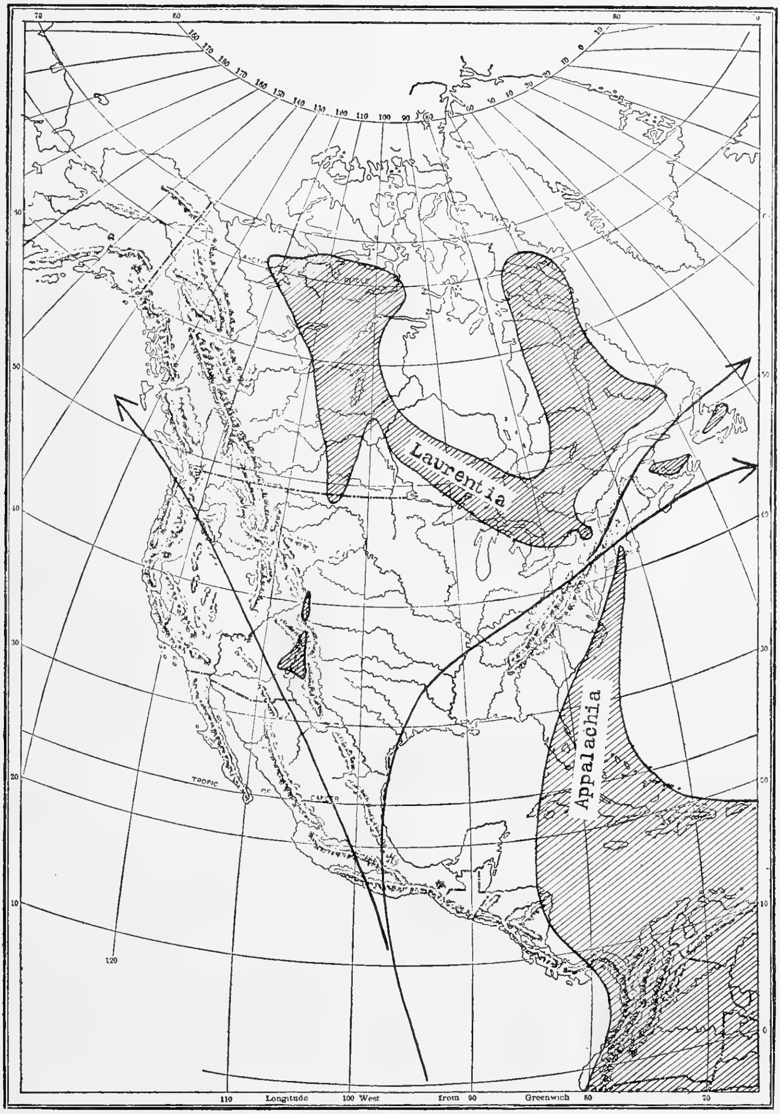


Fig. 2.—Paleogeographic map of North America in early Beekmantownian time, showing extent of maximum transgression and probable currents.

To make a distinct system of them, as has been proposed by some, will not solve the difficulty, because the transitional beds are likely to be of very variable quantitative and chronologic values in different localities. The accepted base of the Ordovicic,—the summit of the Saratoga formation in New York, of the Franconia sandstone in the Mississippi Valley, and of the *Asaphellus homfrayi* beds on the Atlantic coast, is a perfectly satisfactory one, as long as the synchroneity of these formations is granted. (Compare Figs. 1 and 2.)

REGRESSIONAL PHASE OF THE BEEKMANTOWN

As has been fully demonstrated by the author elsewhere[1] and by Berkey,[2] the chief event of Beekmantown time in North America was the widespread regressive movement of the sea and the re-emergence of the continent. The extent of the movement is shown by the extensive disconformity between the Beekmantown and the succeeding Chazy formations. From this it appears that only a narrow trough remained in the Appalachian region as the sole representative of the interior or Mississippian sea, while most of the Pacific coast region, west of the Rocky Mountains axis, was probably uncovered (see map, Fig. 3). In the interior of North America the emergence was accompanied by widespread continental deposition recorded in the St. Peter sandstone. The detailed characteristics of this formation; the all but complete absence of fossils; the cross-bedding shown in many exposures; the rounded character of the sand grains, their grooved and pitted surfaces; the absence of the finer impurities; the uniformity of the size of grain in the same region—all point to long-continued shifting about of these sands by winds, and testify against their marine origin. The inclusions in the quartz grains show them to be derived from the crystalline oldland, the chief source being probably the Canadian shield. In some cases the contact with the underlying formations is abrupt and disconformable, showing that erosion of the uncovered limestones preceded the deposition of the sands. Not infrequently the contact

[1] Grabau, A. W., "Physical Characters and History of Some New York Formations," *Science*, N. S., Vol. XXII., pp. 528 ff., October, 1905; also, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 616 ff.

[2] Berkey, C. P., "Paleogeography of St. Peter Time," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 229–50.

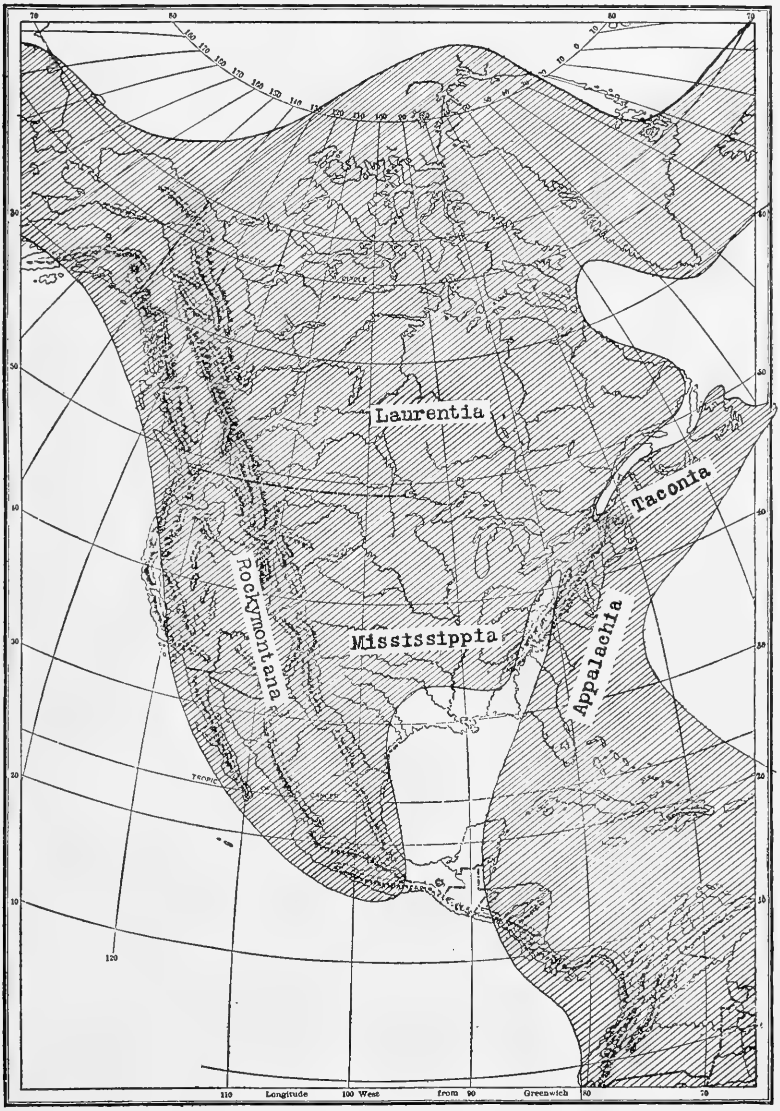


Fig. 3.—Paleogeographic map of North America at the end of Beekmantownian time, showing maximum retreat of the sea.

is as sharply marked as that of aeolian quartz sands found upon the clear-swept limestone floors of some modern deserts.[1] In some cases, however, there appears to be absolute conformity between the St. Peter sandstone and the underlying dolomites, pointing to continuous deposition. Both in Wisconsin and in Minnesota, the lower Magnesian beds are often slightly folded, and the lower St. Peter sandstone is likewise involved in these folds[2] (Fig. 4). The upper St. Peter, however, and the overlying Stones River, which are perfectly conformable, are not involved in these folds. In Minnesota, the Oneota, New Richmond, and Shakopee formations have a combined thickness of 105 to 260 feet. If the Jordan and St. Lawrence beds are regarded as Ordovicic, though they still contain Dicellocephalus, the thickness is increased to 190 feet minimum or 673 feet maximum. The faunas of all the beds of the Lower Magnesian series indicate lowest Ordovicic and close relationship to the Upper Cambric. In the Black River region, Cushing records 20 to 60 feet of lowest Beekmantown (Theresa), succeeded disconformably by Upper Chazy (Pamelia and Lowville limestones). The base is probably not exposed in this section, the basal sandstone, called Potsdam by Cushing, being most likely of later age. In the Mohawk Valley, 350 feet of Beekmantown (Little Falls dolomite) is followed disconformably by Upper Chazy (Lowville); but here, too, the base of the Beekmantown is not shown, and hence the true thickness is unknown. In the Lake Champlain region the Beekmantown is 1,800 feet thick; in southern Pennsylvania 2,250 to 2,300 feet; in central Pennsylvania nearly 2,500 feet; and in the Arbuckle Mountains of Oklahoma 1,250 feet. In all these localities, except central Pennsylvania, the upper limit of the Beekmantown is marked by a dis-

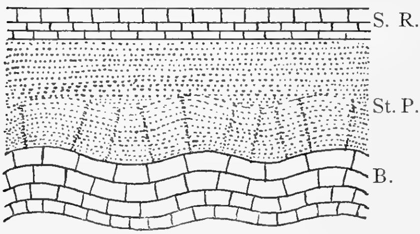


Fig. 4.—Showing the relationship of the Upper Stones River (S. R.) and lower Beekmantown (B.) Beds of Minnesota and the included St. Peter (St. P.) (Redrawn from Hall and Sardeson.)

[1] Compare Zittel, *Beiträge zur Geologie und Palaeontologie der lybischen Wüste.*

[2] Hall and Sardeson, *Bull. Geol. Soc. Amer.*, Vol. III., pp. 354, 355.

conformity, and the highest beds are thus wanting. In Center County, Pennsylvania, the upper beds appear to be completely represented. They are succeeded by 2,335 feet of dolomitic limestones, classed by Collie with the Beekmantown, but for reasons given elsewhere[1] referred by the author to the Chazy; and by 235 feet of limestones of Upper Stones River (Upper Chazy) age. The succession seems to be uninterrupted, placing this section in the region of non-emergence, while the others cited belong in that of emergence during late Beekmantown time. The section in central Pennsylvania does not, however, show the base of the Beekmantown, which is thus thicker than 2,500 feet (see Fig. 5). There seems no reason for doubting that the higher

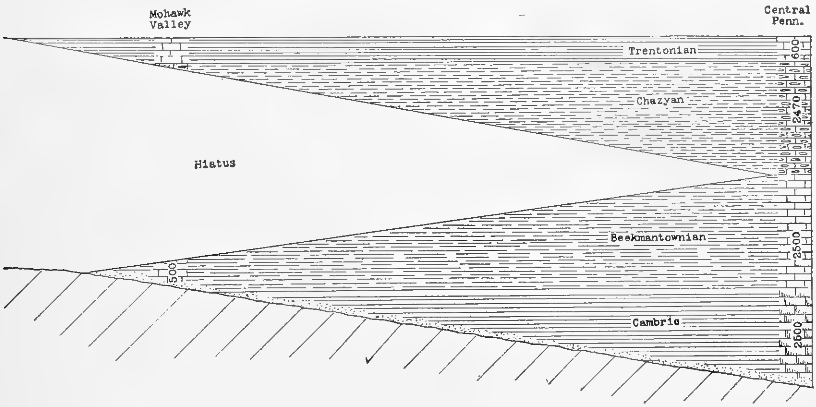


Fig. 5.—Diagram showing relationships between the Mokawk and Central Pennsylvania sections and the character of the overlaps and "off-laps," with the progressively decreasing hiatus.

beds of the Beekmantown were progressively deposited during the slow retreat of the sea, and that each higher member had, in general, a smaller areal distribution than the preceding one. On this view the successive members have the "off-lapping" arrangement of shingles, except that the earlier and lower formations are continuous beneath the higher ones. This is regressive overlap or "off-lap," and seems to supply the only rational explanation answering to the facts. To assume that the whole of the Beekmantown was deposited before retreat began, not only makes the negative diastrophic movement a cataclysmic one, where the positive movement was a very slow

[1] *Types of Sedimentary Overlap*, p. 619.

and regular one, but also necessitates the further assumption of an enormous erosion during the succeeding transgressive movements, which not only removed the greater part of several thousand feet of strata over the northern United States area, but also the whole of the extensive Canadian deposits of Beekmantown which must have reached far toward the Arctic regions, if the entire Beekmantown was deposited as a transgressional series. Aside from the fact that erosion would scarcely be very active during a positive diastrophic movement or transgression of the sea, it can hardly be assumed that such extensive erosion preceded the deposition of the St. Peter sandstone and the Chazy formation. Moreover, the intimate relation between the Lower St. Peter and the underlying Lower Beekmantown demands a close succession in deposition, the lower sand beds being probably deposited by the shoaling sea itself. If that is indeed the case, no higher dolomites of Beekmantown age than are now found ever existed in the Minnesota area.

West of the Rocky Mountains, the basal Uinta quartzite is chiefly if not wholly a continental deposit of pre-marine Cambric time, 12,000 feet or more in thickness. Upon this enormous basement series the eastward-transgressing Cambric sea laid down its progressively overlapping strata, the upper beds of the series being reworked during the progress. The transgressing sea apparently did not reach the region of the eastern Uintas, where the basal quartzite is succeeded by the Lodore shales. From these shales Powell reported Carboniferous (Mississippic?) fossils,[1] and he gives evidence of the existence of a disconformity between these shales and the basal sandstone. Weeks[2] identifies the Lodore with the Iron Creek shales of Berkey, which lie between the Uinta and the Ogden quartzites, and which Berkey correctly correlates with the Cambro-Ordovicic Ute limestone of the Wasatch. Weeks fails to recognize that, as Berkey has shown, the Ogden quartzite has united with the Uinta in the eastern section, the intervening shales having wedged out. The Lodore of the eastern Uintas thus lies above the Ogden horizon, and corresponds to a part of the overlapping Mississippic series (see Fig. 6).

The Lower Ordovicic retreat is shown in the western section by the

[1] *Geology of the Uinta Mountains.*

[2] *Bull. Geol. Soc. Amer.*, Vol. XVIII, pp. 435, 436.

appearance of the Ogden quartzite and conglomerate, which bears internal evidence of continental, chiefly river, origin; and to all appearance represents the sand and gravel wash which followed the retreating sea westward, and which was probably in large part derived from the basal Uinta quartzites, with which the Ogden seems to become confluent in the eastern Uintas.[1] This quartzite rests on higher beds in the western sections than in the eastern, thus showing the same relationship to the underlying series that is exhibited by the St. Peter sandstone. In the western Uintas it is underlain by 1,200 feet of shales, regarded as Cambric, though the highest beds may represent the Lower Ordovicic. In the Wasatch Mountains the Ute limestone, 2,000 feet thick, and of Cambro-Ordovicic age, lies between the Ogden and Uinta quartzites. In the Eureka section of central Nevada, the Pogonip limestone, 2,700 feet thick, underlies the Eureka quartzite, the westward continuation of the Ogden. The Pogonip represents, in its basal portion, the transition beds from the Upper Cambric, but corresponds mostly to the Beekmantown of eastern North America. Beneath it are 6,200 feet of fossiliferous shales and limestones of Cambric age. Here, as in the eastern region, succes-

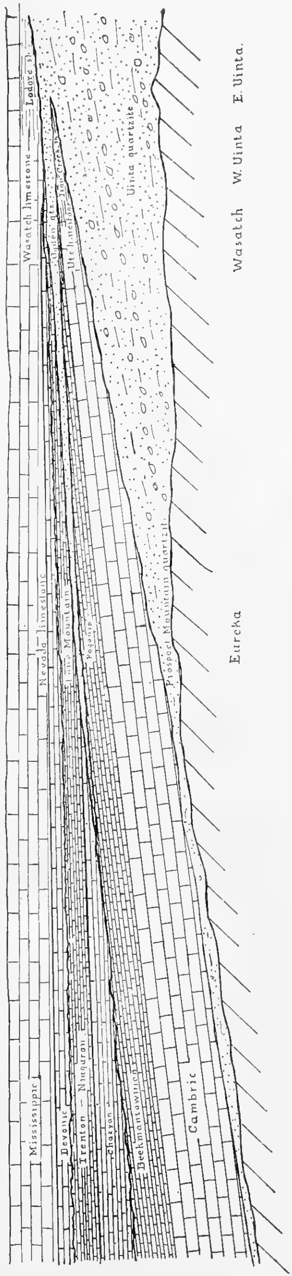


Fig. 6.—Diagram showing the relationships and overlaps of the Paleozoic strata west of the Rocky Mountains.

[1] Berkey, *Bull. Geol. Soc. Amer.*, Vol. XVI, pp. 517–30.

sively higher beds appear beneath the quartzite in the direction of the retreat, indicating continuous deposition during the slow regressive movement of the sea, this being checked as the localities successively emerged.

A widespread negative diastrophic movement is thus shown to have taken place over the whole of the North American continent, accompanied and followed by the spread of subaërial clastics over most of the area. At least 2,500 feet of calcareous strata were deposited in the non-emerging areas, and most of this constitutes the depositional equivalent of the retreatal movement (see map, Fig. 3).

The Beekmantown faunas.—The Beekmantown faunas are, so far, best known from the Lake Champlain region, the Mingen Islands, and the Newfoundland section. The Lake Champlain region, including the Phillipsburg section of the Canadian extension, has furnished a considerable number of species. Its distinctive character will be seen on consulting published lists.

The Pogonip limestone of Nevada contains mostly species unknown outside of this formation in the West, though a number of them have been referred by Walcott to eastern species, largely Trenton and Chazy types. In almost all such cases, however, the identification is provisional, and regarded by Walcott himself as doubtful. There is nothing in the character of the fauna which positively demands its reference to either the Chazy or Trenton, as has been done.

GRAPTOLITE FACIES OF THE BEEKMANTOWNIAN

In the Hudson and St. Lawrence valleys the Beekmantown is represented by the lower portion of the Hudson River shales, above the beds with *Dictyonema flabelliformis.* Some 340 feet of strata appears to be referable to this series, of which the lower 300 feet constitutes the first and second Deepkill zones, synchronous with the Upper Point Levis zone of Canada and the St. Anne zone of Newfoundland. Here the genera Chlonograptus, Goniograptus, Tetragraptus, and Phyllograptus (*P. anna*), with *Didymograptus bifidus*, characterize a succession of zones recognizable in various parts of the world. The upper forty feet of this series (third Deepkill zone)

is characterized by *Diplograptus dentatus* and *Cryptograptus antennarius.* This zone has been correlated by Ruedemann with the Chazy limestones of the Champlain region, but it probably is also referable to the Beekmantown, since most of its characteristic types occur in the Upper Arenig of Great Britain. The world-wide distribution of these graptolite faunas suggests that they were dispersed by strong currents sweeping through an open channel along the inner or western side of an Appalachian continent and its New England extension (Taconia). The fauna was most likely spread from Australia by strong currents passing up the west coast of South America and entering the Appalachian synclinal trough, along which it flowed northeastward to Newfoundland. Northwestward of this zone of mud-deposition we find the limestone of the Beekmantown grading down, by the addition of quartz grains, into the basal quartz sand, without intervening mud deposits (see map, Fig. 2).

With the progress of Beekmantown retreat the channel was closed, a land bridge connecting Taconia with Laurentia. Thus the mud deposition was checked and only a moderate thickness of Beekmantown strata of this type was formed. This represents, therefore, largely the lower part of the Beekmantown. As has been stated, it is probable that the Chazy is unrepresented by deposits of mud, the channel remaining closed until the end of that period, when it reopened through the progress of Chazy transgression, and the Normanskill beds, with a late Chazy (Lowville) and Black River graptolite fauna, were formed. In spite of some similarities, the *Diplograptus dentatus* and the *Coenograptus gracilis* zones are quite distinct, the important genera, Odontocaulus, Thamnograptus, Corynoides, Azygograptus, Leptograptus, Nemagraptus (Coenograptus), Dicellograptus, and Dicranograptus, appearing suddenly. In like manner, the characteristic Beekmantown genera, Dendrograptus, Goniograptus, Loganograptus, Dichograptus, Tetragraptus, Phyllograptus, and Didymograptus, continue through the third Deepkill zone, only the last of them extending into the Normanskill zone. Certain long-lived genera, Desmograptus, Diplograptus, Clonograptus, Climacograptus, and Cryptograptus, begin in the third Deepkill zone and extend through all or most of the remaining Ordovicic. Of the genera in common between the third Deepkill and the Normanskill,

Didymograptus is represented by three species,[1] all common in the Normanskill, and all distinct from those of the lower horizons, where eighteen species are recorded. Of the genera beginning in the third Deepkill, or Point Levis zone, Climacograptus has only one species in the lower zone, which is not known above that zone, while there are thirteen species, most of them abundant, in the Normanskill; Cryptograptus has one species in the lower and two others in the higher zone, common in each case; Desmograptus has two species in the lower and one in the higher, the latter rare; Diplograptus has four species in the lower and thirteen in the higher horizon, all distinct; while Clonograptus has two rare species in the lower and nine in the upper, mostly common. It is thus seen that there are no species in common between the two zones, and the most characteristic genera of each are unknown or rare in the other. On the other hand, six out of the twenty-four species listed by Ruedemann for the third Deepkill zone, or 25 per cent., occur also in one or both of the lower zones. Its relationship to that and distinctness from the Normanskill zone thus becomes evident. The forty feet of the third Deepkill zone probably represents the last deposits in an already shoaling and contracting channel before interruption took place, this break continuing to the end of Chazy time, when a new graptolite fauna came into existence.[2]

On the whole, the Beekmantown represents one of the large stratigraphic divisions of the Ordovicic of North America. Its fauna is essentially a unit, and although the succeeding Chazy fauna is in part, at least, derived from the Beekmantown, its distinctness is nevertheless marked. The Beekmantown corresponds to a great negative diastrophic movement, with the exception of the lower portion, and its thickness (2,500 feet where fully developed) shows that it represents fully one-third of the entire Ordovicic series, and presumably represents one-third of Ordovicic time. From this it follows that the Beekmantown alone represents the Lower Ordovicic in North America, the Middle Ordovicic beginning with Chazy deposition. The term *Beekmantownian* has therefore been proposed as the North American equivalent of Lower Ordovicic, while the

[1] Varieties are here classed as species.

[2] See Ruedemann, *Graptolites of New York*, Vols. I and II.

term Canadian becomes obsolete. The *Beekmantownian* corresponds essentially to the *Arenigian* of England and its continental equivalent.

B. THE MIDDLE ORDOVICIC OR CHAZYAN

In its maximum development, the Chazy shows nearly 2,500 feet of limestones, many portions of which are highly fossiliferous. An apparently complete development of this series, resting with conformity upon the Beekmantown, is described by Collie from Center County, Pennsylvania. Here 2,335 feet of dolomitic limestones, with fossils poorly preserved, succeeds the Upper Beekmantownian; and above this is 235 feet of fossiliferous limestones of Upper Stones River (Upper Chazy) age, succeeded in turn by the Black River. Sedimentation seems to have been continuous throughout, and this section may therefore be regarded as typical of the Mid-Ordovicic in its entirety. In southern Pennsylvania, Stose reports a disconformity and hiatus between the Beekmantown and Chazy (Stones River) limestones. The latter are from 800 to 1,000 feet thick, and are succeeded by the Chambersburg limestone (100 to 600 feet thick), which carries an Upper Chazy and Black River fauna. Continuous deposition seems to have obtained between the two series. In the Lake Champlain region, a hiatus also exists between the Beekmantown and Chazy, with the result that only about 900 feet of Chazy occurs in this region below the Black River beds. In western Newfoundland at least 2,000 feet of strata is referable to this series, the succession being conformable. Here, however, the upper limit of the Chazy is not known, the highest bed (P) being succeeded by continental sediments of much later age.

In the Arbuckle Mountains the hiatus between Beekmantown and Chazy is marked by a sandstone, and only the upper 2,000 feet of the Chazy (Simpson) is shown, followed by Black River. The Chazy is absent in the Mohawk Valley, except for a few feet of Lowville which lies disconformably upon the eroded surface of the Lower Beekmantown (Little Falls dolomite), and is conformably succeeded by the Black River. In the Black River Valley, at Watertown and northward, the sedimentation from Lowville to Black River is continuous and gradual. Cushing[1] finds in the Theresa quadrangle

[1] *Bull. Geol. Soc. Amer.*, Vol. XIX, pp. 155–76.

from 115 to 215 feet of strata beneath the Black River, and resting disconformably upon the Lower Beekmantown (Theresa formation), which, with its basal sandstone (called Potsdam by Cushing), has a maximum thickness of 140 feet. Cushing restricts the term Lowville to the upper 75 to 85 feet of pre-Black River strata, separating the lower part, on paleontologic grounds, as the Pamelia limestone. At Lowville and elsewhere this series overlaps the Beekmantown, resting with a basal sandstone upon the crystallines. The Pamelia fauna is an Upper Stones River fauna, according to Ulrich, while the fauna of the Lowville is compared with that of the Upper Chazy.[1]

In the Canadian region, only Upper Chazy (Lowville and possibly the Pamelia equivalent) is present. In a number of localities it rests directly upon the pre-Cambrics, generally with a basal sandstone (St. Mary's sandstone). In some cases, however, lower beds (Beekmantown, with basal sands) have been reported. In Minnesota and Wisconsin the Upper Chazy is called Stones River, though it represents only the upper part of the Stones River formation of Safford's Tennessee section where the thickness is 360 feet. The Minnesota beds are 32 feet thick and are probably the exact equivalent of the Lowville of New York, though the fauna is stated to be more like that of the Pamelia. The relation of these beds to the underlying St. Peter sandstone is significant, since the contact is perfectly conformable and gradational. Moreover, Stones River fossils (*Hormotoma gracilis*, *Lophospira perangulata*, etc.) are found in some of the upper beds of the St. Peter, showing that with the advent of the Chazy sea, the sand dunes of the St. Peter desert were incorporated as basal sands in the overlying formation. This meant, of course, a slight reworking of the sands by the encroaching sea. That this reworking did not reach to the bottom of the St. Peter, at least not in all cases, is shown by the persistence of the folds and faults in the lower beds, whereas they are absent in the upper (see Fig. 4). A comparison of sections shows that in general lower beds of Chazy age appear progressively above the St. Peter as we proceed southward and eastward. The relationship of these beds to the St. Peter has not been discussed in detail, but it is certain that in some localities, at least, the gradation observed in Minnesota obtains. The relation-

[1] See Cushing, *loc. cit.*

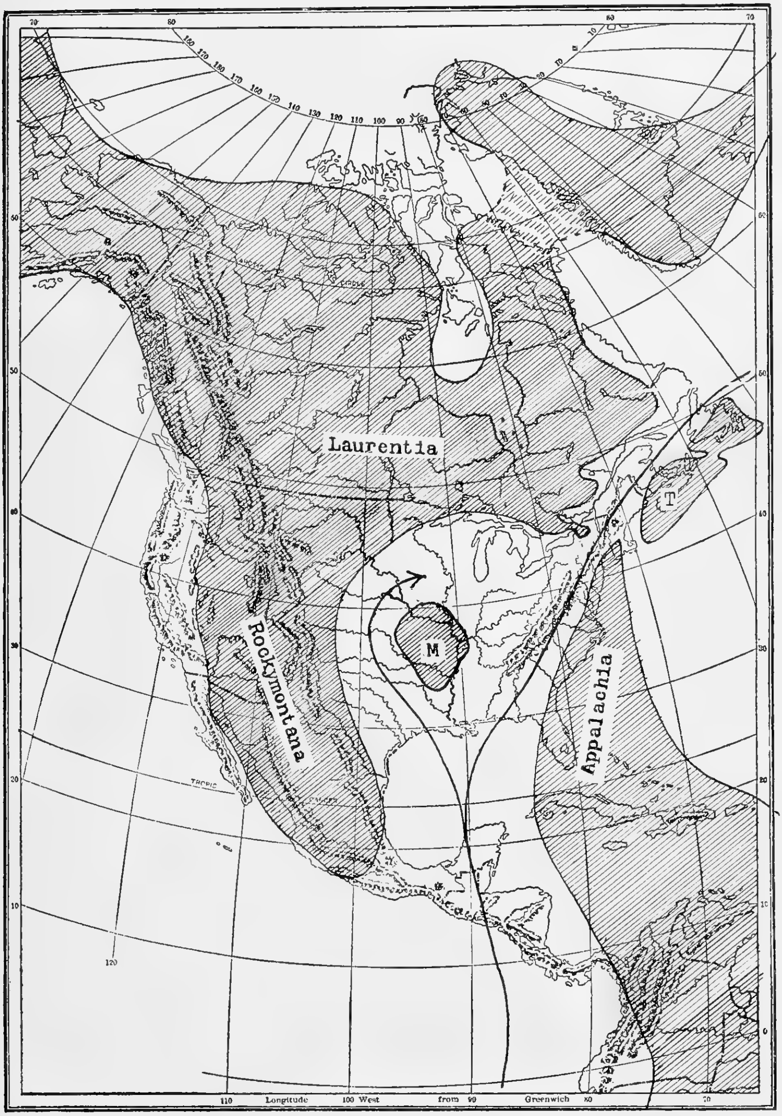


Fig. 7.—Paleogeographic map at the end of Chazy time and the probable currents. M, Ozark Island, the remains of Mississippia T., Taconic Island.

ship is, accordingly, that of a progressively overlapping transgressional series to its basal bed, and this is the interpretation favored by all the sections. The Chazy was, in fact, characterized by a transgressive or positive diastrophic movement throughout (barring possible minor oscillations), and therefore only the higher beds are found in the region of late submergence. The thickness of the formation beneath the Black River, forms in general a reliable guide to the division of the Chazy represented, though of course there may be discovered some minor disconformities which would vitiate detailed correlations made on this basis in a given region.

No unquestionable Chazy beds have been reported from the Pacific region, where the Trentonian seems to rest directly upon the Eureka quartzite in Nevada, and either Siluric or Devonic succeeds the Ogden quartzite of the Wasatch, with Mississippic beds succeeding the same in the Uintas. The west coast transgression was, therefore, less pronounced, the Nevada region remaining still uncovered at the end of Chazy time (see map, Fig. 7). If Chazy beds occur in the West, they must be sought for in western Nevada and California. It is, of course, impossible to say how much has been removed by late Ordovicic erosion. It is not improbable that the Chazy extended east of Eureka, Nev., but was removed again in Upper Ordovicic time.

The Chazy fauna.—At the beginning of Chazy time, the Champlain gulf was entirely distinct from the Appalachian gulf, there being a land connection between the Laurentio-Mississippian continent and the united Appalachia and Taconia, or Ancient New England continent (see map, Fig. 3). The faunas were thus to a large extent distinct, representing, in fact, the Atlantic and the southern type. The southern type was, in general, the Stones River type of fauna; the character of which may be seen by consulting published lists. The Atlantic type is seen in the fauna of the Champlain basin, which admits of a threefold division, a lower (Div. A) with *Orthis costalis*; a middle (Div. B) with *Maclurea magna*; and an upper (Div. C) with *Camarotoechia plena.*

That these two types of faunas were not wholly distinct in middle and later Chazy time is shown by the occurrence of true Champlain species of Mid-Chazy age, including *Maclurea magna* in the middle

portion of the "Stones River beds" of southern Pennsylvania; and of Upper Chazy species, including *Camarotoechia plena*, in the Chambersburg limestone of the same region. Whether this implies an Appalachian extension of the Champlain gulf or a connection with the Atlantic in the southern part of North America must be determined by further detailed study. It is probably true, however, that the open passage along the west border of Appalachia and Taconia, through which the mud-bearing currents swept in early Beekmantown time, and which formed the route of dispersal for the graptolite fauna of that age, was not re-established until late Chazy or Black River time. This accounts for the slight development of the graptolite-bearing shales referable to the Chazy in the Hudson and Levis series. The disconformity which represents this interruption would probably be difficult to trace in strata of such similar lithic characters.

THE BLACK RIVER FORMATION

This formation is widespread, having been traced by its fauna from the Champlain Valley to the upper Mississippi and southward to Oklahoma and the Appalachians. Over this area it forms an excellent datum plane from which correlation of overlying and underlying formations becomes possible. Its thickness is never very great; it is only 7 feet in the type region, at Watertown, N. Y., 50–60 feet in Minnesota, less than 100 feet in Oklahoma, 90 feet in southern Pennsylvania, and 70 feet in the Champlain Valley. Faunally, it represents a transition between the Chazy and Trenton, as will be seen by consulting published lists. Its classification with either the Chazy or the Trenton is therefore permissible. Since the formation represents the unchecked continuance of the transgressive movement initiated at the opening of Chazy time, its classification with that series of strata as Mid-Ordovicic is perhaps most desirable.

THE NORMANSKILL BEDS AND FAUNA

The Normanskill shales are generally regarded as representing the shale facies of the Lower or Middle Trenton. Ruedemann, in his recently published monograph parallels them with the *Lowville*, *Black River*, and *Lower Trenton*.[1] In Rysedorf Hill, the shale includes a conglomerate, the pebbles of which, regarded as nearly syn-

[1] *Graptolites of New York*, Part II.

chronous with the shale, carry a Lowville–Black River–Lower Trenton fauna, with some elements (*Christiania trentonensis*, *Ampyx hastatus*, Remopleurides, Sphaerocoryphe, Cybele, etc.) suggesting a geographic connection with the European sea of that time. The typical graptolite fauna of the Normanskill includes more than 60 species in all, though the widely distributed forms are much fewer. The more constant and characteristic species comprise: (1) *Coenograptus* (*Nemagraptus*) *gracilis;* (2) *Dicellograptus sextans;* (3) *D. divaricatus;* (4) *Dicranograptus furcatus;* (5) *D. ramosus;* (6) *Diplograptus foliaceous;* (7) *D. angustifolius;* (8) *Climacograptus parvus;* and (9) *C. bicornis*. Of this list, Nos. 1, 2, 4, and 8 are the most characteristic index fossils of this zone. *Didymograptus sagitticaulis*, Gurley, and *Climacograptus scharenbergii*, Lapw, may also be mentioned as characteristic though less widely distributed forms.

Besides the numerous localities along the Hudson and St. Lawrence valleys, this fauna is known from Maine and New Brunswick. In the Appalachian region it is definitely known only from New Jersey and from Bebb County, Alabama; it is also doubtfully identified from western Virginia and eastern Tennessee. It has been found in Arkansas and the Ouachita Mountains of Oklahoma; in southern Nevada (Belmont and Letson peak); and in the Kicking Horse Pass of the Rocky Mountains of British Columbia. It is also known from New South Wales and Victoria in Australia; and from southern Scotland, Scania, and France.

The distribution of this fauna is such as to suggest an eastern and a western land mass (Appalachia and Rockymontana) of low relief, with currents of the Gulf Stream type sweeping along their inner borders and distributing the graptolites, which became entombed in the muds that accumulated in these channels of moderate depth. The division of what was probably a single great current, sweeping north along the South American coast, and carrying the graptolites from Australia, was probably due to the existence of an Ozarkian island or Archipelago, along the borders of which, as in Arkansas and Oklahoma, were deposited some of these black muds. One arm of the divided current swept along the east coast of Rockymontana to the Arctic Sea of Alaska; the other along the west coast of Appalachia, past a Newfoundland island, and across the North Atlantic

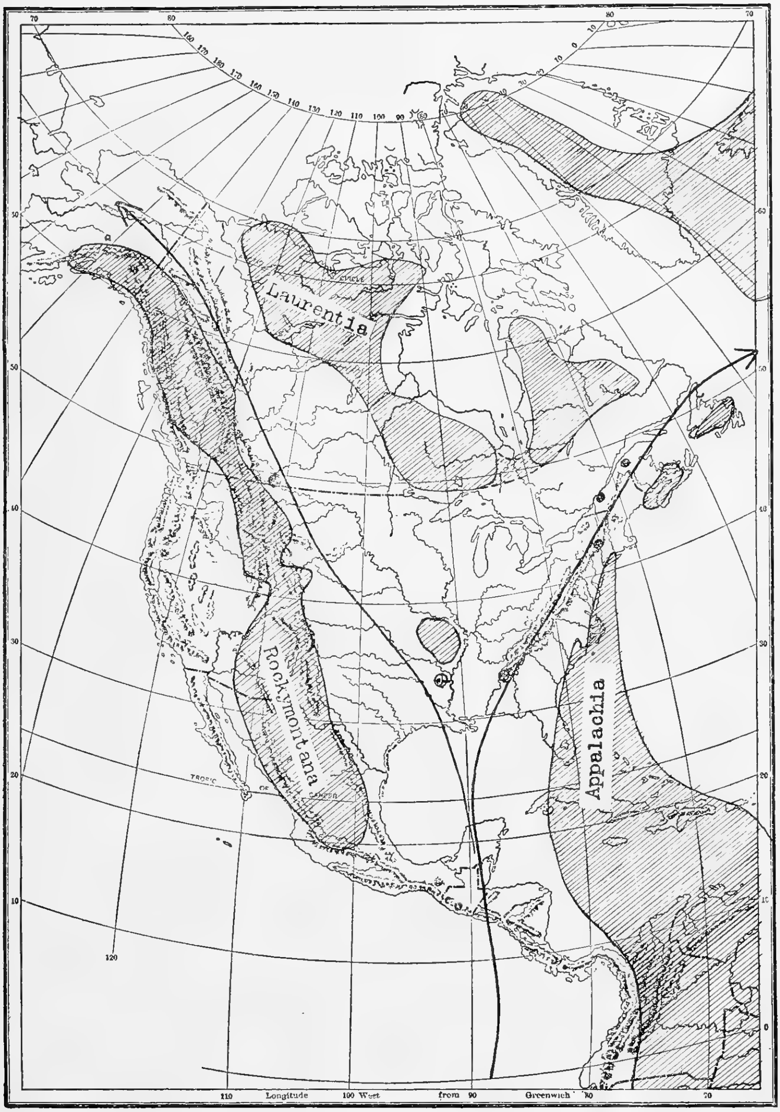


Fig. 8.—Paleogeographic map at the end of Trenton time, showing second maximum transgression in the Ordovicic. The currents are indicated for Black River time. ⊕ indicates distribution of B. Normanskill graptolites.

to northern Europe (see Fig. 8). Within the protected interior sea, limestones (Upper Stones River and Black River) accumulated. Limestones accumulated also along the shores of Laurentia (Canadian shield) in the St. Lawrence channel, the two types of sediment and faunas thus occurring side by side. There is no need for postulating a dividing ridge in this channel, for the faunas and sedimentation would remain different as long as the different physical conditions persisted.

In Great Britain and elsewhere in Europe the zone of *Coenograptus gracilis* forms the summit of the Middle Ordovicic. The next succeeding zone (Hartfell shales of the Moffat district) is of Upper Ordovicic or Caradocian age. This begins with the zone of *Dicranograptus clingani*, which in North America is represented by the Magog shales or *Diplograptus amplexicaulis* zone, which succeeds the Normanskill beds.

The diastrophic movement, which in North America resulted in the emergence of most of the continent at the end of Lower Ordovicic time, was likewise marked, though to a less extent, in Europe. Lamansky has recently shown[1] that between Baltic Port and the banks of the river Volkov, the Lower Ordovicic beds (Etage B) show the progressive off-lapping structure characteristic of a retreatal or beveled-off series of sediments. At Baltic Port only the *Megalaspis planilimbata* zone (BIIα) occurs. Farther east, at Reval, the higher *Asaphus bröggeri* zone (BIIβ) and a part of the *Asaphus lepidurus* zone (BIIγ) have appeared. In the extreme east of the gouvernement of St. Petersburg, on the Volkov, the whole of BIIγ, and the *Asaphus expansus* zone (BIIIα) have come in above the others. The line of disconformity and erosion is marked by slight irregularities, by glauconite, iron oxide, and phosphate concretions, rarely by siliceous sediments. Above the erosion plane, the beds of BIIIβ and BIIIγ (zones with *Asaphus raniceps* and *Asaphus eichwaldi*) show progressive overlapping, the latter being represented only by clastic material at Baltic Port. Above these lies the Echinosphaerites limestone C, which shows continued westward overlapping.

[1] Lamansky, W., "Die ältesten silurischen Schichten Russlands," *Mém. du Comité Geol.*, N. S., Livr. XX, 1905.

The regressional movement here indicated appears to coincide with that of North America, but the transgressive movement seems to have begun somewhat earlier, unless the Lower Ordovicic is regarded as ending with the *Asaphus expansus* zone.

C. THE UPPER ORDOVICIC OR TRENTONIAN

Most current classifications of the Ordovicic formations of North America unite the Black River and Trenton limestones under Clarke and Schuchert's term Mohawkian, which is made synonymous with Middle Ordovicic. As we have seen, the Middle Ordovicic is represented by the Chazyan, which in its maximum development includes some 2,500 feet of limestone strata, and is therefore comparable in

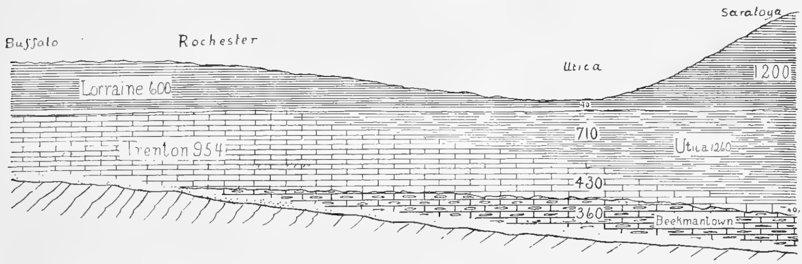


Fig. 9.—Diagram showing the relationships of the Ordovicic strata of New York, between Saratoga and Buffalo.

magnitude and, inferentially, in time value, to the Beekmantownian or Lower Ordovicic. The fauna of the Chazyan is, moreover, distinct from both preceding and succeeding faunas, and the natural dividing-line between the Middle and the Upper Ordovicic is shown, by paleontologic, stratigraphic, and diastrophic reasons, to be within or above the Black River horizon; a division coinciding with that made in the European series. The Trenton limestone of America is not a stratigraphic unit, but, as has been repeatedly demonstrated by Ruedemann and noted by many observers, it is the limestone phase of a series which elsewhere is in part or mostly represented by Utica shale. In the Mohawk Valley the dividing-line between Utica and Trenton is a line constantly rising to the west, the transition being in some cases abrupt, though probably in most cases it is gradual. Ruedemann has pointed out the progressive increase in thickness

westward of the limestone, and corresponding decrease in the shale; the former increasing from 40 feet at Saratoga to 430 feet at Utica, and to 954 feet at Rochester, while the latter decreases from 1,260 feet to 710 feet to probably zero over the same localities (Fig. 9). In the South Mountain region of southern Pennsylvania, the Chambersburg limestone of Stones River, Black River, and Lower Trenton age is succeeded by 1,000 feet of gray fossiliferous and dark bituminous shales, with intercalated limestone members in the basal portion which carry a Lower Trenton fauna. The shales contain *Leptobolus insignis*, *Triarthrus becki*, and Utica graptolites, and are succeeded by a sandstone with the fauna of the Eden beds of the Cincinnati region, formerly identified as Utica, but now regarded as younger than that formation. In central Pennsylvania, some 600 feet of Trenton succeeds to Black River, and is followed by 650 feet of Utica shale. In this zone also we have some typical Trenton species, such as *Dalmanella testudinaria*, *Isoteles platycephalus*, etc., associated with *Triarthrus becki* and other Utica species. The various sections clearly show that along the western border of the Appalachians, dark graptolite shales continued to form in Upper Ordovicic time, while westward from this the Trenton limestone represents the calcareous phase of the Utica-Trenton series (see map, Fig. 8).

THE TRENTON–UTICA GRAPTOLITE FAUNAS

The Normanskill fauna is succeeded by that of the Magog shales or zone of *Diplograptus amplexicaulis*—the upper Dicellograptus zone of Gurley. This represents, according to Lapworth, highest Llandeilo or lowest Caradoc, and forms a transition to the true Utica fauna. Many of its species are characteristic of the Hartfell shales (Caradocian) of southern Scotland, though others are equally characteristic of the Normanskill and Glenkiln shales. Ruedemann regards this fauna as a relict of the preceding one.

> The Didymograptidae have vanished entirely, and the Dicranograptidae almost; only the long range forms, *Dicranograptus ramosus* and *nicholsoni*, are still observed, and the Diplograptidae . . . . hold now almost entirely the field, with the genera Diplograptus, Climacograptus, and Cryptograptus.[1]

The fauna is best developed near Quebec and at the north end of Lake Memphremagog, only fragmentary representation occurring

[1] *Op. cit.*, II, 30.

in New York. The fauna is rapidly changing, the true Upper Ordovicic faunas are appearing, and soon the typical Utica fauna, with *Glossograptus quadrimucronatus*, *Climacograptus typicalis*, *Corynoides curtus*, and, less frequently, *Leptograptus flaccidus*, *Dicranograptus nicholsoni*, and *Climacograptus putillus* is established. The association of typical Utica graptolites with characteristic Trenton limestone fossils, as *Trocholites ammonius*, *Cameroceras proteiforme*, and *Schizocrania filosa*, bears on the previously discussed question of the synchroneity of the Utica and Trenton.

Climacograptus typicalis, the typical Utica species, is reported by Winchell and Ulrich from the Fusispira and Nematopora beds of the middle Galena of Minnesota. Since the Galena of that section follows directly upon the Black River, this occurrence is only a short distance above the base of the Trenton, which is thus indicated to be the western limestone equivalent of the Utica shale of the east. As already noted Ruedemann has cited abundant evidence of the gradual westward extension of the successively higher zones of the Utica, and the replacement of the limestone phase (Trenton) by them. The Galena-Trenton limestone of the Lake Winnepeg region contains *Dictyonema canadense* (Whiteaves), *Thamnograptus affinis* (Whiteaves), and the typical Utica species, *Climacograptus typicalis* (Hall). Whiteaves concludes that the Galena-Trenton of Lake Winnepeg "most probably represents the whole of the Utica and Trenton formations, inclusive of the Galena."[1]

THE CINCINNATI GROUP

This is the upper calcareous phase of the latest Upper Ordovicic, and comprises, in ascending order, the Eden, Maysville, and Richmond. The Eden was formerly correlated with the Utica, but the underlying Trenton mainly represents that formation. The Eden is in part equivalent to the Frankfort shales, though the occurrence of *Climacograptus typicalis* in the Eden strata would favor its former correlation with the Utica. The Maysville represents later Lorraine as developed in New York, though the fauna, being that of a calcareous facies, is markedly different.

Ulrich has reported a disconformity at the base of the Eden, in the Cincinnati section, but this, if it exists, does not appear to be

[1] Quoted by Ruedemann, *op. cit.*, II, 28.

of great importance. It certainly does not represent Utica shale. There is, however, a marked and widespread disconformity between the Lower and Upper Trentonian, the late Richmond resting on Trenton or even earlier beds. This is observed throughout the Rocky Mountain area, the upper Mississippi region, and to a less extent in other sections. It signifies a retreat of the sea, probably at the end of Trenton time, and a return during late Richmond time.

THE TRENTON–CINCINNATI FAUNAS

While on the whole the faunas of the Trenton limestone and of each one of the three divisions of the Cincinnati group are sufficiently distinct, so that it is not difficult to recognize the exact horizon of each by a careful analysis of the fauna, there is, nevertheless, a unity in these faunas, which shows their unmistakable relationship to one another and their distinctness from the preceding faunas. It is this broad similarity of faunas, together with the distinctness from the preceding faunas, the intimate relation of the limestone to the Utica shale which it replaces, and the moderate thickness of the formation in its best development, as compared with that of the Chazy and Beekmantown, that has led me to place the Trenton limestone in the Upper Ordovicic. In England, the Upper Ordovicic or Caradocian (Bala) is characterized by the same faunal elements which here appear for the first time. The more common species characterizing the Upper Ordovicic from the Trenton up, and occurring in most if not all of its beds, include *Rafinesquina alternata*, *Plectambonites sericea*, *Dinorthis subquadrata*, *Plectorthis plicatella*, *Dalmanella testudinaria*, *Platystrophia biforata; Protowarthia cancellata*, *Liospira micula*, *Clathrospira subconica*, *Trochonema umbilicatum*, *Cameroceras proteiforme*, *Calymmene callicephala*, *Isoteles gigas*, *I. maximus*, and *Ceraurus pleurexanthemus*.

Some of these species begin in the Black River or even in the Upper Stones River, but they are most characteristic of the higher horizons.

THE CONTINENTAL PHASE OF UPPER ORDOVICIC TIME

The later epochs of Upper Ordovicic time were characterized by continental or non-marine sedimentation in the Appalachian region. The earliest of these is the conglomeratic and quartz-sand

series found directly overlying the fossiliferous marine Ordovicic of southern Pennsylvania, and generally classed by Pennsylvania geologists as "Oneida." This is a gray to white, rarely red, conglomerate and quartz sandstone with rounded quartz pebbles and characterized by extensive cross-bedding. Its maximum thickness today is in Bald Eagle Mountain, near Tyrone City, Blair County, Pennsylvania, after which locality I originally named it.[1] This name, however, was preoccupied, and the formation under consideration is therefore called the Bald Eagle conglomerate, this ridge being due to the resistant character of this and the succeeding formation. At Tyrone the thickness is 1,319 feet, while thirty miles to the northeast, at the Bellefonte Gap, through the same ridge, the thickness is only 550 feet, and the formation is divisible into a lower hard gray sandstone without pebbles, 170 feet thick, and an upper greenish-gray somewhat ochery and micaceous sandstone with intercalated greenish shales. One hundred and sixty miles northwest from Tyrone, at Buffalo, this formation (Oswego sandstone) is 75 feet thick. It is here a white quartzite lying below the red Queenston shales, and represents only the upper layers of the gradually spreading fan of clastic sediments. In central New York the Oswego is 185 feet thick at the falls of the Salmon River. It there succeeds the Lorraine beds with perfect conformity, some Lorraine fossils extending into the lower Oswego.

There can be little doubt that these beds represent the northern and western attenuated upper beds of the Bald Eagle conglomerate of Pennsylvania, unless indeed they belong to one or more distinct fans with a source in the north.

The character of the rock, its cross-bedding, and absence of fossils indicate continental origin, and this is also shown by the nature of the overlap, which is that characteristic of river deposits. The intimate relationship between the Lorraine and the highest bed (Oswego sandstone) of this formation, indicates that the age of this formation is Lorraine. The Bald Eagle conglomerate is everywhere succeeded by the red shales and sandstones of the Juniata formation. In southern Pennsylvania this overlaps the preceding formation and rests directly upon the Eden sandstone. The forma-

[1] *Science*, N. S., Vol. XXIX, p. 355.

tion here contains remnants of the Lorraine fauna with *Byssonichia radiata* and other types. These beds are clearly the lower Juniata, for the base of the series is seen in contact with the Bald Eagle conglomerate not far away. The maximum thickness of the Juniata in central Pennsylvania is from 1,000 to 1,200 feet. On the Niagara, the corresponding Queenston shale is 1,100 feet thick, and it thins away almost wholly before reaching Michigan, where only a few red beds mark the summit of the Ordovicic.

The Juniata has all the characters of deposits in arid regions. The total absence of fossils, except where, at the beginning, a lagoon extended north into Pennsylvania, is a striking feature. That fossils could be preserved in the formation is proved by the occurrence

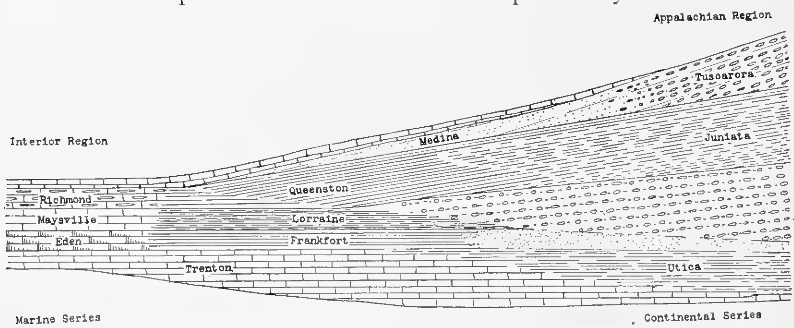


Fig. 10.—Diagram showing relationships of marine and continental upper Ordovicic and lower Siluric strata. The conglomerate beneath the Juniata is the Bald Eagle, and beneath it is the Eden sandstone.

of Lorraine species in the basal beds. Their absence from the others must then be taken as indicating that none were inclosed in the strata. This absence of fossils, together with the character of the beds, their red color, frequent mudcracks, and numerous clay slugs or "Thongallen" in the sands, and the aeolian cross-bedding, all point to a continental origin, under conditions of semiaridity and tropical climate. That the Juniata and Queenston beds are equivalent, and were formed under the same physical conditions, cannot be doubted. Their correspondence in thickness indicates an almost complete equivalency. They may, however, have distinct sources, one in the southeast and the other in the north. In western New York the Queenston shales are succeeded by the true Medina sandstones and green shales, which are partly fossiliferous, carrying a true

Niagaran fauna. This fixes the age of the Queenston and Juniata as Richmond, so far as their major portion is concerned; though, as already noted, the lower part must be considered as Lorraine (see Fig. 10).

In eastern Tennessee a second deposit of red sands of this period forms the Bays sandstone. This is from 1,100 to 1,300 feet thick in its maximum development near Loudon, but thins away by overlap in all directions. In some localities, as at Walker Mountain, it is fossiliferous, carrying the late Lorraine fauna with *Byssonychia radiata*, *Modiolopsis modiolaris*, etc. Wherever the contact with the underlying Sevier shale is exposed, it is seen to be a gradational one, the fossils extending part way up into the red beds. The basal white bed, comparable to the Bald Eagle conglomerate, if it ever existed here, was overlapped by the Bays, the portion east of the overlapping edge having been removed by erosion. The Bays may be regarded as an independent fan, or group of fans, of red sedimentation with a distinct center of supply.

The correlation of this series of continental sediments with the contraction of the sea known to have occurred in Upper Ordovicic time has not yet been attempted. It is not improbable that the initial uplift of the land which caused the retreat of the sea, also initiated the strong river-activities which resulted in the formation of the Bald Eagle conglomerate and sandstone. This probably corresponded to the period of folding of the Ordovicic and earlier strata in New England and northward. If that is the case, the emergence was probably post-Trenton, falling in early Lorraine (Frankfort or Eden) time and extending toward the end of Lorraine time. The period of red sedimentation in the east may have coincided with the period of erosion in the upper Mississippi and Rocky Mountain areas, and deposition of the Richmond in the narrow interior basins. The late Richmond expansion may coincide with the climatic change indicated by renewed river deposits of white quartzose material.

D. THE LOWER SILURIC OR NIAGARAN

The following divisions of the New York Niagaran are in common use as the North American standard: Guelph, Lockport, Rochester, Clinton.

The Clinton of the best known section, that of western New York, begins with the true or Upper Medina, which, along the Niagara River, admits of a number of subdivisions, which are, however, of only local significance.[1] The total thickness is nearly 125 feet, with 25 feet of white quartzose sandstone (Whirlpool sandstone) at the base, and about 8 feet of a similar sandstone at the top. The middle series consists of red sandstones and green and gray sandstones and shales. The red sandstones generally show aeolian cross-bedding and appear to have accumulated above water. The green sandstones and shales are fossiliferous. The white Whirlpool sandstone exhibits beach features,[2] and probably marks the advance of the sea, though it is likely that the sand was originally dune sand, as suggested by A. W. G. Wilson.

The fossils are generally most abundant in the shales and thin-bedded sandstones. The heavy-bedded sands are either free from fossils or have only scattered shells of Lingulae. At Lockport and elsewhere some layers are crowded with gastropod shells. The characteristic fossil, *Arthrophycus harlani* is everywhere in New York restricted to the upper beds just below the upper white sandstone.

The fossils so far obtained from the Medina are: *Arthrophycus harlani* Conr.; *A.* sp.; *Daedalus* several species; *Scolithes verticalis* Hall; *Dictyolithes beckii* (Conr.); "*Fucoides*" *auriformis* and "*F.*" *heterophyllus; Holopea fragilis* Hall; *Lingula cuneta* Conr.; *Whitfieldella oblata; Camarotoechia* sp.; *Uncinulus stricklandi* (Sowerby); *Plectorthis medinaensis* sp. nov.; *Rhipidomella* sp.; *Pentamerus* sp.; *Modiolopsis orthonota; M. primigenius; Pterinea cf. emacerata; Pleurotomaria pervetusta* Conr.; *P. littorea* Hall; *Holopea* (?) *conridea; Bucanopsis trilobatus* (Conr.); *Oncoceras gibbosum; Orthoceras* sp.; *O. multiseptum* Hall; *Ascidaspis* sp.; *Dalmanites* sp.; *Isochilina cylindrica* Hall.

This is a Lower Siluric fauna, and favors more especially the Clinton and Rochester faunas. It is so far known only from western New York, with the exception of *Arthrophycus harlani*, which is widely distributed. In western New York this species occurs at the top of a heavy-bedded unfossiliferous sandstone with an aeolian type

[1] See *Bull. 45, New York State Museum*, pp. 88–95.

[2] Fairchild, H. L., *Amer. Geol.*, Vol. XXVIII, 1909.

of cross-bedding; and just below the upper white quartzite. In east-central New York it is found at the base of the Oneida conglomerate, which is the approximate equivalent of the upper white sandstone of Niagara. In the Appalachians, it is found mostly in the upper part of the Tuscarora and Clinch sandstones, the stratigraphic equivalent of the Medina. Sarle[1] has recently interpreted this structure as due to worm borings. So far as I have observed in the field, the raised ridges of this fossil always occur on the under side of the sandstone layers, representing, therefore, the relief molds of grooves generally formed in the clays beneath. These grooves had a median ridge and a regular succession of transverse ridges separated by broad concave grooves. A similar structure, known as Climatichnites trails, but of a much broader type, occurs in the Potsdam sandstone of New York. Woodworth[2] has suggested that it represents the trail of an animal comparable to some extent to modern Chiton.

There are no known remains of organisms in the Medina or Clinton capable of making such an impression, and the organism which made it either had no parts capable of preservation or else it was a terrestrial type frequenting the shores and sandy wastes, where it left its trail in the mud, but not its remains, just as the Triassic Dinosaurs left their footprints but seldom their skeletons.

The Tuscarora has a thickness of 820 feet in Logan's Gap, Jack's Mountain, Mifflin County, Pennsylvania, but thins perceptibly westward and southward, being 400 to 500 feet thick in Bald Eagle Mountain and 287 feet in Wells Mountain and the Pennsylvania-Maryland line. This thinning appears to be due to failure of the lower beds, showing a true case of non-marine progressive overlap. In New York, the upper part is represented by the true Medina, which has a thickness of 125 feet, and begins and ends with a pure white quartz sandstone. More strictly speaking, the upper white sandstone alone represents the true Tuscarora, but the lower beds, still partly red, and the shales, probably are the equivalent of the lower reddish sandstones and greenish shales underlying the true white Tuscarora, and sometimes referred to the Upper Juniata. The Oneida conglomerate of central New York, 40 feet thick, is likewise

[1] *Rochester Acad. of Sci. Proc.*, 1906, No. 4, p. 203.

[2] New York State Pal. Rep., 1907, *Bull. New York State Museum, No. 69*, p. 959.

the representative of the upper part of Tuscarora, though it may have had a more local origin.

All of these beds, including the basal white Bald Eagle formation, belong to the much-washed and reworked type of continental sediments, in which concentration of the indestructible quartz had been brought about by long exposure, resulting in the decomposition of all the other minerals, and the removal of the resultant clay and dust by wind and running water.

The Clinton shales succeed the Oneida conglomerate in Oneida and Herkimer counties, New York, and the Upper Medina quartzite in western New York. In the southern Appalachians, the series is largely composed of sandstones (Rockwood), highly impregnated with iron, and often containing beds of workable iron. It is generally succeeded by late Siluric (Monroan) or by Helderbergian or later beds, there being a pronounced disconformity at the summit of the Rockwood throughout. That part of the series in Virginia is of continental origin is indicated by the general character of the rocks, but marine intercalations are not uncommon. In some cases in eastern Tennessee the iron ore itself is fossiliferous, having replaced a marine limestone. In such cases the bulk of the formation is shale. In no case is the original thickness preserved since the formation is everywhere bounded above by an erosion plane. In northern Virginia today the thickness is 750 feet (Piedmont folio), and not over 400 feet in southern Virginia. In southern Tennessee and northern Georgia it is from 1,100 to 1,600 feet thick, decreasing westward and northward. With our present knowledge of the formations, it is safe to say that the eastern sandy phase represents near-shore deposits, if not actually continental conditions, formed probably at the embouchures of several Appalachian rivers; and that westward these deltas merged gradually into true marine deposits, mainly sands and clays, with some limestones intercalated. That the Rockwood represents more than the Clinton of New York cannot be questioned. Where the series is developed in its totality, it probably represents the entire Niagaran, if not a part of the Salinan as well. Along the Alleghany front, fossiliferous shales and iron ores represent this series, with a thickness of not less than 1,000 feet, on the western branch of the Susquehanna. The lower series, 700 feet thisk, consists mainly of

fissile shales, including an iron sandstone, and with Buthotrephis in the upper part. This is succeeded by 110 feet of calcareous fossiliferous shales; and this by 230 feet of fossiliferous shales and limestones with a Niagaran fauna. Above this follows 350 feet of red shales, probably representing the Upper Salina, and separated by a hiatus from the fossiliferous Niagaran shales.

In eastern New York, at Swift's Creek, the type locality for the Clinton, this formation is 226 feet thick and is followed by 5 feet of Niagaran and then by the red shales of the Upper Salina. On the Niagara River the Clinton shale with the two succeeding limestones has a total thickness of 32 feet, followed by 68 feet of Rochester shale. The total of the Niagaran, including the Guelph, is from 270 to 325 feet, as shown by borings. This is followed by Lower Salinan. In the Rochester region the Clinton has a thickness of 80 feet, including the Irondiquoit or upper limestone (17 feet), which Chadwick refers to the Rochester. The eastward thinning of the Upper Niagaran beds indicates either that these beds were eroded before the deposition of the red shales, probably during the Shawangunk epoch (see beyond); or that the Rochester-Lockport of the West is in part represented by Upper Clinton in the East. The Guelph element may never have extended to the Clinton type region, which may have been above water and so subject to erosion.

The most typical section of the North American Lower Siluric or Niagaran is found in Wisconsin, where the series exceeds 700 feet in thickness and is wholly calcareous. At the base of the series, however, in a few localities, as at Iron Ridge, occurs a remarkable iron ore, composed of flat lentils of varying size and heaped together in a mass strongly suggestive of dune history. This idea is borne out by the position of these pellets, which are not laid flat, as would be the case if they were deposited by water, but are placed in all positions. Cross-bedding and irregular wedging-out of layers and a rapid thinning away of the entire mass, further suggest such an origin. There are no fossils in the ore, and it rests upon an uneven surface of the Upper Ordovicic, with a layer of highly polished clay pebbles marking its base. The interpretation of this formation that I am at present able to advance is that of a dune of calcareous pellets of concretionary or phytogenetic origin, similar to the oölite dunes of Great Salt

Lake and other regions; and that these dunes were subsequently altered, by replacement, to iron ore.

The series of limestones overlying this basal bed, or resting directly upon the Ordovicic, is for the most part richly fossiliferous. Some of the beds, as the Racine and the Coral Beds, are characterized by reefs of Stromatoporoids and other corals, widely distributed and connected by more or less barren lime sands (calcarenytes) which resulted from the erosion of the reefs. Some beds are of shallow-water origin and bear the marks of periods of exposure, resulting in the formation of mud cracks, etc. The fauna is more or less uniform throughout, and the series represents continuous deposition, recording only minor oscillatory movements. Southward we find these beds extending through northern Illinois, Indiana, and Ohio, with a more or less uniform fauna, while further south, in the Cincinnati and western Tennessee regions, part of the limestones is replaced by shales and new faunal elements appear.

The typical Niagaran fauna.—This is to be found in the strata of the Wisconsin section and in their continuations in northern Illinois, Indiana, Michigan, and Ohio. It is an exceedingly rich fauna, and, as Weller has ably demonstrated, has many elements in common with the Mid-European Siluric. The Stromatoporoids abounded on the reefs of the Coral Beds and the Racine. They have not been much differentiated in Wisconsin, but from other sections, especially Canada and Ohio, a considerable number of genera and species have been recognized. Corals abound, especially Halysites and Favosites, while Bryozoa are most common in the shales of New York and the southern area, Fistulypora making extensive reefs in western New York. The brachiopods, except the large Pentamerus, are likewise more characteristic of the shales. Crinoids, Cystoids, and Trilobites appear to be most common in the limestones of the interior.

The Guelph fauna.—This fauna demands a special notice, because it is so distinct in its eastern manifestations. The peculiar aspect of the fauna is produced by the great Trimerelloid brachiopods (*Trimerella grandis*, *T. ohioensis*, *Monomorella prisca*, etc.); the peculiar corals Pycnostylus; the large pelecypod *Megalomus canadensis;* the gastropods *Pycnomphalus solarioides;* and the genera

Euomphalopteris, Hormotoma, and Coelidium, together with various species of Eotomaria and other Pleurotomarioids, and the remarkable *Trematonotus alpheus*. This represents a new invasion of the interior sea, probably from the rich fauna of northern Europe. In North America the physical conditions accompanying this spread of the fauna appear to have been shoaling of the water and inclosure and restriction of the interior sea. The fauna appears as early as the lower Coral Bed in Wisconsin, while the Guelph element of the Racine fauna is very marked. *Trimerella grandis*, *Megalomus canadensis*, *Pycnomphalus solariodes*, *Coelidium macrospira*, and *Sphaeradoceras desplainense* are among the species which occur in association with the rich Racine fauna. Many of the typical corals, brachiopods, and other types continue into the Guelph in Wisconsin, the fauna not differing markedly from the Racine. In New York Clarke and Ruedemann have found the Guelph fauna intercalated between the normal manifestations of the Niagaran coral fauna (Lockport), and it appears that in the Canadian type region alone does it occur in its purity.

THE ATLANTIC AND SOUTHERN NIAGARAN

The Atlantic Niagaran has generally been recognized as belonging to a distinct province separated by a land barrier from the interior sea. This is made evident not only by the distinctness of the faunas, as exhibited in the Anticosti group and the development in Maine and New Brunswick, but also by the fact that the entire interior Appalachian region contains only shallow-water or continental deposits, indicating a continuous land mass in the East. That the Anticosti fauna nevertheless communicated with the interior is shown by its occurrence in Georgia and elsewhere in southeastern United States. This occurrence represents either a distinct embayment from the Atlantic, or the fauna migrated into the interior, going around the southern end of Appalachia, which may then have been separated from South America. An invasion of the interior from the south is indicated by the fauna of the Cape Girardeau or Alexandrian[1] formation of Illinois and Missouri, and perhaps also by the fauna of the

[1] See Savage, T. E., *Amer. Jour. Sci.*, Vol. XXV (1908), pp. 431–44; Schuchert, *Jour. Geol.*, Vol. XIV (1906), pp. 728, 729.

St. Clair[1] limestone of Arkansas. The Alexandrian series of Savage contains many types unknown from the true Niagaran, some Ordovicic genera also being present (Rafinesquina, Platystrophia, Rhynchotreta, Zygospira). Few typical Niagaran species occur, but the presence of the genera Favosites, Atrypa, Whitfieldella, Homoeospira, Schuchertella, Chlorinda, and Lichas (Metopolichas) indicates the Siluric age of this fauna. It probably represents an invasion from the south before the Niagaran transgression from the north had reached the southern Illinois region. Northward, in central and northern Illinois, this fauna seems to be wanting, the true Niagaran fauna here succeeding the Cincinnatian.

The Alexandrian is succeeded disconformably by 30 to 75 feet of limestones with a Lower Niagaran fauna. A transgression is indicated by the fact that "where the formation is thinnest, it is the lower, and not the upper layers that are absent."[2] The Niagaran fauna includes: *Favosites favosus*, *Halysites catenulatus*, *Atrypa rugosa*, *Orthis flabellites*, *O. cf. davidsoni*, *Plectambonites transversalis*, *Stricklandinia triplesiana*, and *Triplesia ortoni;* which grouping, as stated by Savage, corresponds to that of the Clinton of the Dayton, Ohio, region.

The invasion of the interior by a southern fauna, in later Niagaran time, seems to be indicated by the later Siluric formations of Tennessee and possibly in part by the Louisville limestone of Indiana and Kentucky. The higher beds of western Tennessee, called by Foerste[3] the Brownsport beds, and subdivided into the Beech River, Bob, and Lobelville formations by Pate and Bassler[4] contain faunas apparently not found in the typical or northern Niagaran formations, and which are well developed in the underlying series, named, in ascending order, Clinton, Oswego, Laurel, Waldron, Lego, and Dixon.

[1] Van Ingen, Gilbert, "The Siluric Fauna near Batesville, Ark., Part I," *Schoo of Mines Quarterly*, Vol. XXII (April, 1901), pp. 318–29.

[2] Savage, *op. cit.*, p. 435.

[3] Foerste, A. F., "Silurian and Devonian Limestones of Western Tennessee," *Jour. Geol.*, Vol. XI, pp. 554–715.

[4] Pate, W. F., and Bassler, R. S., "The Late Niagaran Strata of West Tennessee," *Proc. U. S. Nat. Mus.*, Vol. XXXIV, pp. 407–32. See also Roemer, *Die silurische Fauna des westlichen Tennessee*, in which the fauna of these higher beds is described.

E. THE MIDDLE SILURIC OR SALINAN

This is typically known only from New York, Michigan, western Ontario, northern Illinois, and Ohio, and is everywhere a series of more or less calcareous shales and gypsiferous beds, with salt beds up to 100 feet in thickness. The maximum development is in central New York and southern Michigan, where it exceeds 1,000 feet in thickness. In western New York it is only 350 feet thick. The only fossils known from the beds are from the lower (Pitsford) shales, where they represent the last survivors of the Guelph. They are chiefly Eurypterids (Hughmilleria, Eurypterus, etc.) and occur in muds alternating with dolomites carrying a Niagaran fauna. The Eurypterid fauna also occurs in the mud layers in the Shawangunk conglomerate, which hardly admits of any other interpretation than deposition by torrential rivers. This would make the Eurypterid fauna a fresh-water fauna, an interpretation which best corresponds with the distribution of these fossils geologically as well as geographically. The Salina series is best understood as a desert deposit. The absence of organic remains (with the exceptions noted), known to be abundant in all modern salt deposits of sea-margin origin; the thickness of the salt beds; their limitation to circumscribed basins,[1] the red color of the lower shales, their mud cracks, "Thongallen," etc., all point to a continental origin. The absence of true marine strata of Salina age[2] and erosion of the surrounding Niagaran beds further indicate that North America was above water. The salt was derived from the marine limestones of Niagaran and earlier age.

THE GREEN POND SHAWANGUNK CONGLOMERATES AND SUCCEEDING RED SHALES

The general retreat of the sea at the end of Niagaran time was marked in the east by an uplift followed by continental sedimentation. The series began with a conglomerate (Green Pond) 1,500 feet thick in northern New Jersey, but thinning northward to 500 feet at Ellenville (Shawangunk conglomerate), to 200 feet at Rosendale, and to nothing at Rondout. Southward and westward it thins

[1] See Walther, *Gesetz der Wüstenbildung*. Lack of space forbids the full discussion of this interesting problem. It will be treated at length in another paper.

[2] The so-called marine Salina of Maryland is of Monroan age.

to 700 feet at the Delaware water gap, to 400 feet at the Lehigh, and to less southward. The thinning is by failure of the lower beds, showing this to be a true non-marine overlap, and therefore stamping the series as of river origin. The Eurypterid layers in the upper beds are probably contemporaneous with the basal Eurypterid beds of the Salina of New York. The succeeding series of Longwood shales resembles the Juniata-Queenston, and, like it, has all the earmarks of a continental series formed under semiarid conditions. They thin from 2,385 feet in New Jersey to 120 feet at Cornwall, 75 feet at High Falls (High Falls shale); and 25 feet at Rosendale, and disappear farther north. Southward they thin likewise, while westward only the upper 400 feet of the series is shown in the red Lower Salina shales of Ithaca and Syracuse, New York, where they are succeeded by salt deposition and less than 200 feet at Buffalo. Like the conglomerate, the shales thin by failure of the lower beds, i. e., by non-marine overlap away from the source of supply.

F. THE UPPER SILURIC OR MONROAN

This is typically developed in southern Michigan, Ohio, and western Ontario, where it is divisible into Lower Monroe or Bass Islands series, 500 feet thick, or more; middle Monroan or Sylvania sandstone 30 to 150 feet thick; and Upper Monroan or Detroit River series, 300 to 400 feet thick.[1] The entire series is involved in gentle folding of early Devonic age, the Dundee resting upon the eroded surfaces of various members of the series.

The Lower Monroan represents an invasion from the Atlantic across Maryland, Pennsylvania, and southern Ohio, to Michigan and probably Wisconsin. Western Ontario was involved, but apparently not western New York. The fauna is Upper Siluric, genetically related to the Manlius limestone fauna, and, like it, representing an Atlantic type. The Upper Monroan fauna, on the other hand, is of a distinct type, especially in the lower members (Flat Rock, Amherstburg, and Anderdon beds). Besides being related to the later Niagaran fauna, it has a new coral and brachiopod element suggestive

[1] See Sherzer and Grabau, *Bull. Geol. Soc. Amer.*, Vol. XIX. The full discussion of these formations and their fauna will appear in the report of the Michigan Survey.

of Devonic affinities. This is further shown by the occurrence of Panenka and Hercynella in these beds. The highest division (Lucas) is characterized by gastropods, most nearly related to late Siluric types of northern Europe.

The Amherstburg beds of the Upper Monroan appear to be the chronologic equivalent of the Cobleskill of eastern New York, several characteristic species being common to both. It represents the junction of an eastern and a western sea, and a commingling of the fauna of both. The typical Upper Monroan coral and brachiopod fauna seems to have invaded Michigan from the northwest, a somewhat similar fauna appearing near the headwaters of the Saskatchewan. In Pennsylvania the Lewistown limestone appears to represent this horizon.

The Sylvania sandstone has all the characteristics of a wind-drifted sand. Its cross-bedding is of the aeolian type, its grains well rounded, pitted, grooved, and of uniform size; there is a total absence of impurities, and all the characteristics compare favorably with those of the sands of the Lybian desert of today. It indicates a period of land condition between the retreat of the Atlantic embayment (Lower Monroan) and the Pacific invasion of Upper Monroan time.

G. THE LOWER DEVONIC

The Lower Devonic comprises the Helderbergian and the Oriskanian of Clarke and Schuchert. The Helderbergian includes the Coeymans, New Scotland, Becraft, and Port Ewen. The latter is transitional to the Oriskany, and Chadwick proposes to unite it with that formation.[1] The Coeymans is the direct depositional successor of the Manlius, there being frequently a transitional zone between them, with a commingling of the fossils. The former extent of the Coeymans can be estimated from its occurrence at Syracuse and the uniform character which it maintains in that region. This indicates that the western shore of the Helderberg sea was west of Syracuse and perhaps in the region of Buffalo. The eastern and northern limit of the formation is indicated by its mergence into shore deposits in New Jersey, and the southward overlap of the later formations,

[1] *Science*, N. S,, Vol. XXVIII, p. 347.

the Virginia, western Tennessee, and Oklahoma occurrence of this series beginning with beds carrying a New Scotland fauna.[1]

The emergence of the North American continent at the end of Siluric time was accompanied by the first pronounced doming of the Cincinnati region and basining of the Michigan area. Local oscillations seem to have preceded this, but the first great movement apparently did not occur until the end of the Siluric. Between the Michigan basin and the Cincinnati dome were formed the Wabash anticline and the minor folds of Michigan, Ohio, and Canada. When these regions were again wholly submerged in Mid-Devonic time, the deposits of this later epoch came to rest on the beveled surfaces of various Siluric members (see Fig. 11). A subsequent movement

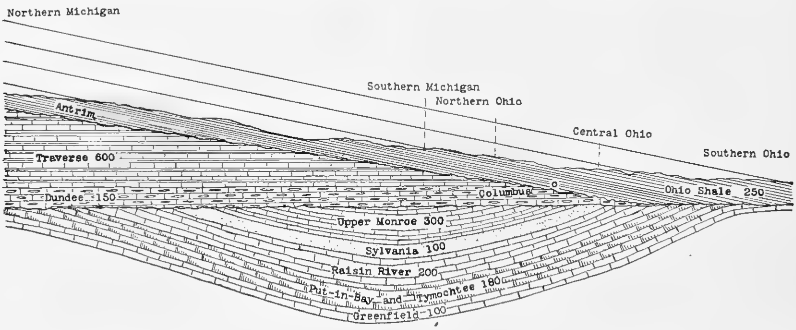


Fig. 11.—Section from northern Michigan to southern Ohio, showing the relationship of the Middle Devonic to the Siluric and of the Upper to the Middle Devonic. O = Olantangy shale.

in the same direction, at the end of Paleozoic time, threw the later beds into similar folds, while emphasizing those of the earlier series.

A marked hiatus occurs between the Helderbergian and Oriskanian. The former series is beveled, so that the Oriskany comes to rest, as it extends westward, upon lower and lower members of the Helderbergian, and finally upon the Manlius, and still farther west upon the Akron dolomite (Cobleskill). This beveling is in part due to retreatal "off-lap" but also to extensive erosion which indicates a time-period of some magnitude for the Oriskany. The depositional equivalent of this hiatus is found in the Gaspe region of Canada, where 550 feet of Oriskanian (Grand Greve limestone) follows

[1] See Grabau, *Bull. 92, New York State Museum.*

1,200 feet of Helderbergian (St. Albans and Bon Ami limestones), the succession being a conformable one.[1]

The Oriskany of the United States is mostly a sandstone, often of pure quartz grains, at other times calcareous. The source of the sandstone is to be sought in the sandstones of the eastern extension of the Siluric and Ordovicic formations, and perhaps in the exposures of the St. Peters and the Sylvania. It seems most likely that the distribution of the sand over eastern North America was largely effected by wind, during the long period of erosion preceding the submergence of the continent. On the westward extension of the Oriskany sea these accumulated sands were reworked and were transformed into the fossiliferous marine sands which they are found to be today. In the east, after a short period of sedimentation, an extensive accumulation of black muds occurred, forming the Esopus-Schoharie shale series. This has its greatest thickness at Port Jervis, whence it thins away in all directions, apparently by overlap. Since the source of the material was clearly in the east, and the overlap is toward the west, north, and south, the formation must be a subaerial fan. This is further indicated by the general absence of fossils, except for occasional intercalations, such as would be expected in a fan of this kind, probably rising but slightly above the level of the shallow Oriskany sea. The continuance of the Oriskany invasion is found in the spread of the limestone with the Schoharie fauna and the succeeding Onondaga submergence. During Onondaga and Hamilton time, continuous deposition and spreading of the seas went on, but at the close of the Middle Devonic, renewed emergence affected most of southern and southeastern United States, accompanied by erosion. This again was followed by the slow resubmergence, which commenced from the north and slowly advanced southward and eastward. The basal member of this transgressing series is the black shale, which, in northern Michigan, is of Lower Devonic (Genesee?) age, but becomes of later and later age southward, at the same time resting always on lower strata. Thus late Upper Devonic (Portage) black shale rests on Lower Hamilton in southern Michigan and northern Ohio; still later beds (Chemung) on the Onondaga (Columbus)

[1] See Clarke, J. M., "Early Devonic History of New York and Eastern North America," *New York State Museum Memoir 9*, 1908.

in central Ohio; while the highest beds rest on Monroan or even Niagaran, in southern Ohio. Continuing southeastward, the black shale rises in the series, until in eastern Tennessee it is of Lower Mississippic age, and rests on Lower Siluric or on Ordovicic strata.[1] (Fig. 11).

DISCUSSION

Professor Calvin

I have studied the Saint Peter sandstone in Iowa, Wisconsin, Minnesota, and Illinois, and nowhere have I seen any marked indications of cross-bedding such as would be consistent with an aeolian origin of the formation. In Iowa and Minnesota there are few structural bedding planes seen in fresh sections, but those that do exist are always horizontal and parallel. Bedding planes are more numerous in this sandstone west of Ottawa, Ill., but they are all precisely of the character one sees everywhere in aqueous sediments. When the Saint Peter is exposed on sloping hillsides, by a process akin to exfoliation, it breaks off in thick flakes parallel to the exposed surface and so often presents a false appearance of cross-bedding; but this feature has no relation to the original structure. One hardly needs to go to the Libyan desert to ascertain the characteristics of aeolian sands. The region around the south end of Lake Michigan affords ample opportunity, nearer home, to study the structural features and topographic forms of wind-blown deposits. I have seen nothing in the Saint Peter suggesting similar origin. Furthermore, the Saint Peter occasionally contains marine fossils, as shown by Winchell and Sardeson.

[1] See Grabau, "Types of Sedimentary Overlap," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 593–613.

CORRELATION TABLE I

		Champlain Valley	Black River and Mohawk Valleys	Western New York	Appalachian Southern Penn. Maryland	Appalachian Tenn.	Interior Cincinnati Region	Interior Upper Mississippi Valley, Ill.
ORDOVICIC	Upper or Trentonian	Utica Trenton	Basal Oswego Lorraine Frankfort — Frankfort Utica Trenton	Queenston Shale Basal "Oswego" s.s. Lorraine Trenton	Juniata Bald Mt. Eden Utica Trenton	Bays Sevier Chickamauga, etc.	Richmond-Maquoketa Maysville Eden ? Point Pleasant	Hiatus and Disconf. Galena
	Middle or Chazyan	? Black River ? C, B, A: Chazy Hiatus and Disconformity	Black River — Bl. Riv. Lowville — Low Pamelia Hiatus and Disconformity — Hiatus and Disconformity	Hiatus and Disconformity	Chambersburg Stones River Group	Hiatus	Black River Upper Stones River Upper St. Peter	
	Lower or Beekmantownian	E, D, C, B, A: Beekmantown	Theresa "Potsdam" — Little Falls Dolomite Hiatus and Unconformity	Lower Beekmantown Hiatus and Unconformity	Beekman-town Shenandoah	Disc. Knox	Hiatus and Disconformity (often masked) Lower St. Peter Lower Magnesian	
Sub-jacent		Upper Cambric	Pre-Cambric	Pre-Cambric	Upper Cambric		Upper Cambric	

A "disconformity," as defined by Grabau, is an erosional unconformity, without discordance of dip.

CORRELATION TABLE II

		Michigan, Ohio, and Canada	West and Central New York	East—Central New York	Helderbergs and Penn.
SILURIC	Upper or Monroan	Hiatus and Disconformity Detroit River Series: Lucas Dolomite, Amherstburg Lime, Anderdon Limestone, Flat Rock Dolomite Hiatus and Disconformity Sylvania Sandstone Hiatus and Disconformity Bass Island Series: Raisin River Series, Put-in-Bay Series, Tymochtee Shale, Greenfield Dolomite Hiatus—Disconformity	Hiatus and Disconformity Akron Dolomite Bertie Waterlime Hiatus and Disconformity	Manlius Limestone Rondout Waterlime Cobleskill Limestone Braymans Shale Binnewater Sandstone Hiatus—Disconformity	Manlius, Rondout, Cobleskill, Rosendale: Lewistown Limest. Hiatus—Disconformity
	Middle or Salinan	Salina—Salt, Gypsum and Lutites	Salina: Camillus, Syracuse, Vernon, Pittsford Hiatus & Disc.	Salina Hiatus, Disconformity	Longwood Shales (High Falls Shales) Green Pond Conglomerate (Shawangunk)
	Lower or Niagaran	Hiatus—Disconformity Niagara / Clinton: Wisconsin: Guelph, Racine, Waukesha, Mayville Hiatus and Disconformity	Guelph Lockport Rochester Clinton.. Clinton Shales and Limestone, Medina sandstone (sens-strict.)	Niagara Clinton (of type-section) Oneida Conglomerate Hiatus and Disconformity	Hiatus and generally an Unconformity
ORDOVICIC		Richmond	Queenston Shales	Frankfort Shales	Hudson Shales

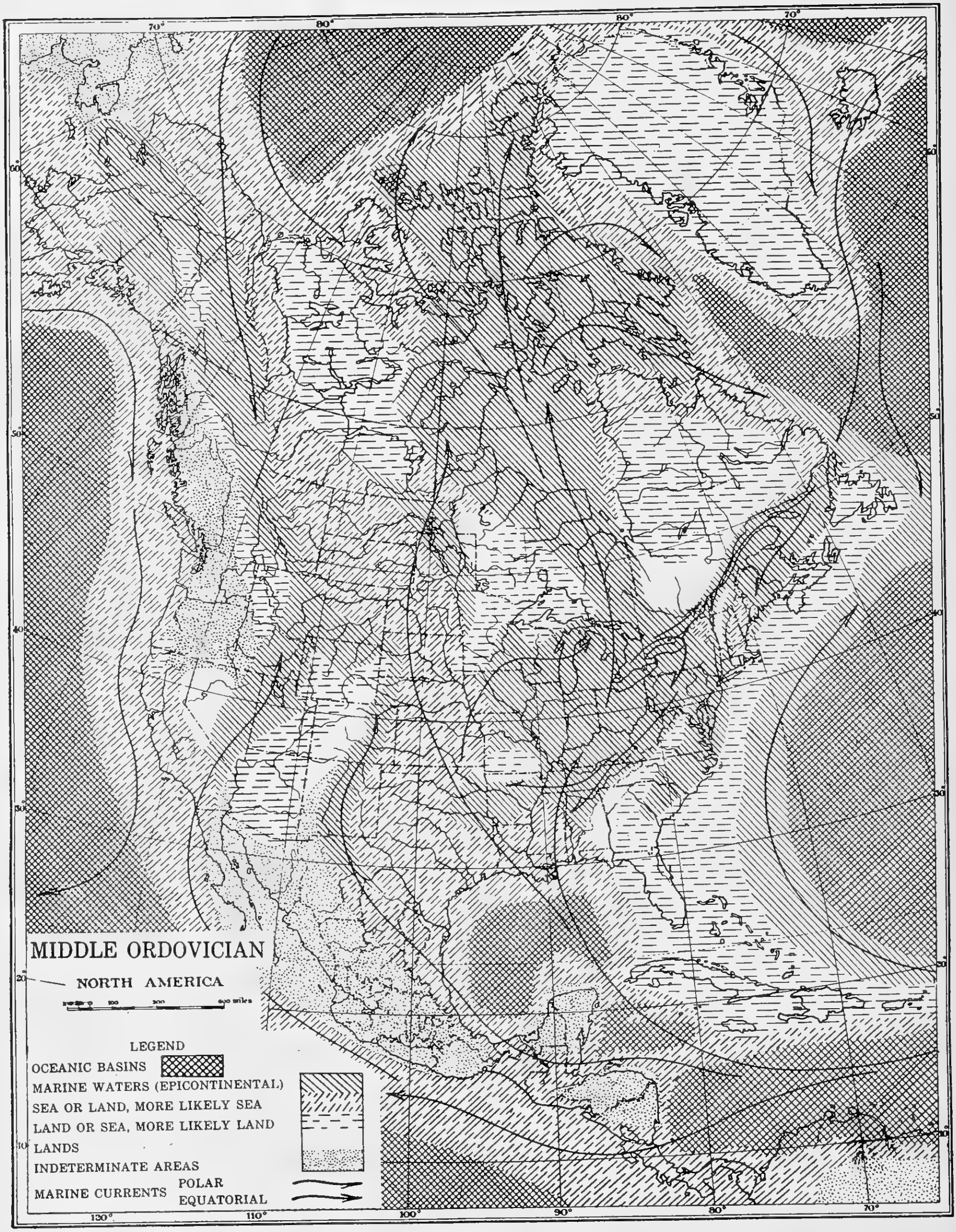
PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

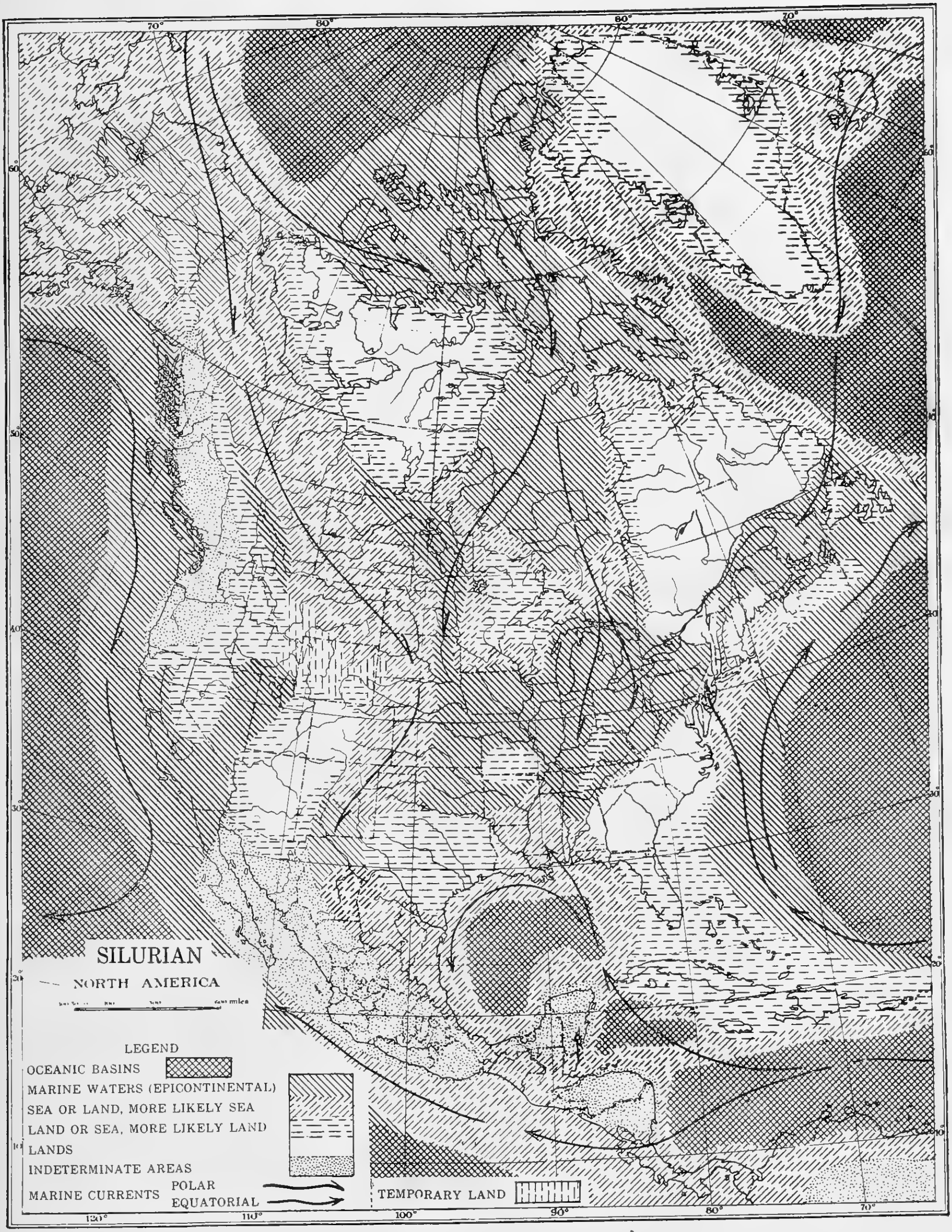
BAILEY WILLIS
U. S. Geological Survey

3. MIDDLE ORDOVICIAN NORTH AMERICA

The passage from the upper Cambrian to the Ordovician appears to be marked in many localities by inconspicuous but notable evidences of non-deposition or erosion which may be attributed to submarine scour or the actual subaërial denudation of low-lying lands. The phenomena differ from those which commonly accompany marked continental deformation. They are believed to have resulted from the deepening of ocean basins which gave rise to a widespread ebb of the epicontinental seas. Effects of continental warping of a subordinate character may naturally have accompanied the sub-oceanic movements. The conditions of oceanic circulation which result from a consideration of the probable distribution of seas and lands are those of general northward currents flowing from the Gulf of Mexico through to the Arctic. They carried with them the characteristic middle Ordovician fauna, which, however, developed local diversities in the eddies of the North American archipelago. In contrast to the central marine currents and their fauna we have the polar southward-trending return currents which may have been congenial to the graptolites. Their distribution would seem to explain the similarity of graptolite faunas in the eastern and western troughs. A peculiar circumstance is suggested in the occurrence of the graptolites in Arkansas. This is recognized on the map by the crossing of the arrows indicating marine currents. It is a well-established fact of oceanography that marine currents pass over or under one another, and this fact affords a possible explanation of the relations which appear to have existed in Tennessee and Arkansas. As a supplemental hypothesis the student should consider Professor Chamberlin's suggestion of an inversion of oceanic circulation which is based upon the possibility that saline equatorial waters may have been denser than, and have sunk beneath, relatively fresh and lighter

[1] Published by permission of the Director of the U. S. Geological Survey.


MIDDLE ORDOVICIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
130°
110°
100°
90°
80°
70°


SILURIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
TEMPORARY LAND
120°
110°
100°
90°
80°
70°

polar waters. The conditions of circulation today are determined by temperature and not by salinity, but the differences of temperature which developed during the glacial period and which still persist are exceedingly great, and it may well be doubted whether temperature had a like effect in Ordovician time, when, as is established by the distribution of faunas, climatic conditions were relatively very equable.

4. SILURIAN NORTH AMERICA

The period covered by this composite map is essentially that of the Niagara. North America was still an archipelago. The continental plateau was widely submerged on the north and was still covered by an interior sea. On the east, however, lands appear to have been elevated in consequence of the Taconic orogenic movements which proceeded from the Atlantic basin, and shallow seas or lands appear to have extended across the region which is now that of the Gulf states. It has been suggested that the sea was generally absent from the western portion of the continent, but recent investigations in Alaska and Utah indicate the presence of a Silurian fauna and we are at least justified in an alternative assumption that marine conditions existed quite extensively, but presented a habitat unfavorable to the rich fauna that occupied the interior Niagaran sea. The conditions of marine circulation appear to have restricted the equatorial currents to the Atlantic on the east and to the Gulf on the south, while the polar currents coming along the coast of Siberia and along Greenland penetrated into the interior sea where the slowly circu lating waters became warm enough to afford a very genial habitat. As in the middle Ordovician, the climatic conditions were equable throughout wide ranges of latitude and marked differences of temperature probably did not exist.

CORRELATION OF THE MIDDLE AND UPPER DEVONIAN AND THE MISSISSIPPIAN FAUNAS OF NORTH AMERICA[1]

STUART WELLER

V

INTRODUCTION

In its essential features a problem in geologic correlation is an investigation in the parallel histories of two or more regions, basins, or provinces, involving the points of contact between these areas. Since it is the fossil faunas which most satisfactorily indicate these points of contact, correlation problems, as applied to the stratified rocks of an age younger than the pre-Cambrian, are largely questions in paleontologic interpretation.

All questions in correlation become progressively more complex as the territory occupied by the faunas under consideration is extended.

[1] Read before Section E of the American Association for the Advancement of Science, Baltimore, Md., December, 1908.

So long as one's observations are restricted to a limited area contained entirely within a single life province, the problems are usually simple, and some beds with similar lithologic characters and similar faunules usually may be traced from section to section without abrupt changes. However, when one's observations extend beyond the limits of a single province or subprovince, the factors in correlation multiply, and frequently the problem becomes one of extreme complexity. In solving these problems the history of the faunas under consideration must be diligently studied in order to determine the elements in their composition, the source of these elements, and their relations one to another, both biologically, geographically, and geologically. The solution also involves the investigation of the paleogeography of the region being studied.

One of the first considerations in connection with any correlation problem is the determination of the several faunal provinces involved and their geographic limits.

NORTH AMERICAN DEVONIAN PROVINCES

Upon the North American continent four well-defined faunal provinces may be recognized in the Devonian strata. These have been designated by Williams:[1] (1) Eastern Border Province, (2) Eastern Continental Province, (3) Interior Continental Province, and (4) Western Continental Province. Although the boundary between the Eastern Continental and Interior Continental provinces is now known to be somewhat different from that assigned by Williams, the names themselves express better than any others which have been proposed the geographic relations of the provinces, and will be used here.

The Eastern Border Province is confined to the easternmost extremity of the continent, within the maritime provinces of Canada and the State of Maine. The outcropping strata of the Eastern Continental Province extend from eastern New York westward across New York and Ontario into Michigan, southwestward along the Appalachians across New Jersey, Pennsylvania, Maryland, West Virginia, and Virginia, also down the Ohio Valley through Ohio, Indiana, and Kentucky to southern Illinois, and southward into Tennessee, northeastern Mississippi, Alabama, and Georgia. Outliers are found in

[1] *Am. Jour. Sci.* (3), XXXV, 51–59.

two regions which are at present wholly isolated from the main body of the province, (1) at Lake Memphremagog near the international boundary between Vermont and Quebec, and (2) southwest of James Bay in Canada. In both of these regions the faunas recognized are so like those of the Eastern Continental Province that there must have been direct communication to them during the life of the faunas.[1]

The Interior Continental Province is typically developed in Iowa, where the Devonian strata are exposed from Muscatine County on the Mississippi River, northwestwardly across the state into the southern border of Minnesota, and it includes also the Devonian strata of Rock Island and Calhoun counties, Illinois, and those of Central Missouri. Beyond this the Devonian beds of Manitoba and the Mackenzie Valley are to be included in this same province, which seems to be connected in a northwesterly direction with the Eurasian Devonian Province. The Western Continental Province is confined to the Great Basin region, and its faunas are best known from the studies of Walcott[2] upon the Devonian faunas of the Eureka District in Nevada.

Since the faunas of the Eastern Continental Province have a more complete and continuous history than those of either of the other provinces, and because they are much better known, their succession is taken as the standard with which the other Devonian faunas of the continent are compared.

THE EASTERN BORDER PROVINCE

For substantial additions to our knowledge of the Devonian faunas of the Eastern Border Province we are recently indebted to Clarke,[3] although contributions of great importance were made many years ago by the Canadian geologists, Logan and Billings. In this region the Helderbergian and Oriskany faunas of Lower Devonian age have a great development, and the faunas of the Gaspe basin give evidence that this region was a center of dispersion of these two faunas. During Middle Devonian time, in this same region, many of the Lower Devo-

[1] For composition of the Lake Memphremagog fauna see Ami, *Ann. Rep. Geol. Surv. Canada*, VII, N. S., 157J; also, Schuchert, *Am. Geol.*, XXXII, 155. For James Bay fauna see Parks, *Ont. Bureau Mines*, *Report for 1904*, Pt. I, pp. 180–91.

[2] *Monograph*, U. S. G. S., Vol. VIII.

[3] "Early Devonic History of New York and Eastern North America," *Mem. N. Y. State Mus. Nat. Hist.*, Vol. IX.

nian types of life persisted to such an extent that the Gaspe sandstone has sometimes been correlated with the Oriskany of the Eastern Continental Province. It has been shown by Clarke, however, that associated with these Lower Devonian types there is a much more important element which allies the fauna with the Hamilton of the interior, the evidence being sufficient fully to justify the correlation of the Gaspe sandstone with the Middle Devonian. The Onondaga fauna is not differentiated in the Gaspe region.

The origin of the Hamilton fauna in the Gaspe basin is assumed by Clarke to have been by migration from the interior by way of the Connecticut and St. Lawrence troughs, and the presence of a similar fauna, showing a mingling of Oriskany and Hamilton types, on the island of St. Helen's near Montreal, gives some strength to such an assumption. However, the possibility of a southern origin, by way of the Atlantic border, should not be lost sight of.

THE EASTERN CONTINENTAL PROVINCE

Middle Devonian of the Eastern Continental Province.—In the Eastern Continental Province two major divisions of the Middle Devonian, the Onondaga and the Hamilton, are clearly recognized. These two faunas, with only minor, subprovincial differences, are persistent throughout the province, in New York, Ontario, Michigan, the Ohio Valley both east and west of the Cincinnati arch, in southern Illinois, and even in northeastern Mississippi and northern Alabama. The Onondaga fauna is in part an evolution product from the subjacent Oriskany, but, in addition, there are included in it at least three conspicuous elements which are entirely new, the corals, the cephalopods, and the fishes. This fauna has a greater distribution to the north than the superjacent Hamilton, it alone being represented in the outlying areas at Lake Memphremagog and James Bay. East of the Cincinnati arch, which was evidently a peninsula at this time, the Onondaga fauna does not extend far beyond the Ohio River, but west of this arch it is clearly recognized as far south as northeastern Mississippi. Throughout this entire area the composition of the fauna is wonderfully uniform.

The origin of the new elements in the Onondaga fauna is not entirely clear. It has been suggested by the writer[1] that these elements

[1] *Jour. Geol.*, X, 429.

have immigrated from the north by way of the tract now occupied by the fauna about James Bay, but there are few facts to support this hypothesis in the known distribution of the Devonian faunas of the Arctic region except the presence of several genera of fishes which occur in the fauna in America and in Devonian strata in Spitzbergen. The mingling of the Onondaga and Oriskany faunas in western Ontario, however, suggests that this was the first point of contact between the immigrant fauna and the pre-existing Oriskany, and would therefore indicate a northern origin for the fauna as a possibility. Ulrich and Schuchert[1] have postulated a southwestern origin, and later Schuchert[2] has suggested a northeastern origin for the fauna through the St. Lawrence Gulf and the Connecticut trough, but there seems to be as little basis for either of these hypotheses as for its northern origin.

East of the Cincinnati arch the Hamilton epoch is initiated by the fauna of the Marcellus shale which is evidently of Atlantic origin in so far as it is not evolved from the Onondaga, but this eastern incursion was of brief duration and did not penetrate to the subprovince lying west of the Cincinnati arch. The Hamilton proper is introduced throughout the province, both east and west of the Cincinnati arch, by the appearance in the faunas of certain peculiar brachiopods which are apparently of southern hemisphere origin, the most conspicuous of which are *Tropidoleptus carinatus* and *Chonetes coronatus*. Aside from this southern element the Hamilton fauna is in large part a derivative from the subjacent Onondaga, a considerable number of species being common to the Hamilton and the Onondaga, while many Hamilton species are closely allied, apparently genetically, to forms in the Onondaga fauna.

In its geographic distribution the Hamilton fauna does not extend as far north as the Onondaga, but it has a greater distribution southward along the Appalachians. West of the Cincinnati arch it is clearly defined in southern Illinois; it is probably present with the Onondaga in northeastern Mississippi, although data are not at hand to make a definite statement to that effect, and it has been clearly recognized in northern Alabama.[3]

[1] *Rep. N. Y. State Pal.*, 1901, p. 652.

[2] *Am. Geol.*, XXXII, 156.

[3] Schuchert, *Am. Geol.*, XXXII, 152.

During the Hamilton period the sea retreated from the northern embayments in the James Bay region and the Connecticut trough, and at the same time it transgressed toward the south and occupied territory which had been dry land during Onondaga time, and connection was apparently established between the eastern and western subprovinces to the south of the Cincinnati arch, which at this time became an island.

Upper Devonian of the Eastern Continental Province.—During Upper Devonian time the faunas of the Eastern Continental Province were far more local in their development than they had been at any time during the Middle Devonian. At no time during the period was there so uniform a fauna as either the Onondaga or the Hamilton had been, distributed throughout the entire province. In the early Upper Devonian time the sea retreated northward from its greatest southward extension of Hamilton time, and later again transgressed toward the south and southwest until it extended much farther than it had in the earlier period, this retreat and readvance being recorded in the unconformity at the base of the Upper Devonian black shale which is commonly exhibited south of the Ohio River and to some extent north of that stream.[1]

The earliest Upper Devonian fauna in the province is the Cuboides fauna of the Tully limestone in New York, characterized by a totally new immigrant element in the Devonian faunas of the province, of which the brachiopod species *Hypothyris cuboides* is the most conspicuous representative. This fauna has been shown by Williams[2] to be closely allied to the Cuboides fauna of the European Devonian which initiates the Upper Devonian of that continent. The Cuboides fauna in America must have had a common origin with the same fauna in Europe, and the path of its immigration into the Eastern Continental Province of North America is commonly considered to have been by way of the Interior Continental Province.

Following the Tully limestone in the northeastern portion of the province is the Genesee black shale with a meager fauna of which the Lingulas are the most conspicuous members. In the southern portion

[1] Data concerning this unconformity have been assembled by Foerste, *Ky. Geol. Surv., Bull. No.* 7, p. 129.

[2] *Bull. G. S. A.*, I, 481–500.

of the province the entire Upper Devonian epoch is represented by a black shale which has been variously called the Ohio shale, the New Albany shale, or the Chattanooga shale, which is widely distributed in southern Ohio, Indiana, and Illinois, in Kentucky, Tennessee, and northern Mississippi, Alabama, and Georgia, and extends westward into northern Arkansas. Throughout the southern portion of the province this black shale rests unconformably upon the subjacent strata, and in some parts of Kentucky, at least, is unconformable upon Middle Devonian limestones. In the Ohio Valley the fauna in the basal portion of the black shale indicates its Genesee age,[1] but as the shale was a transgressing formation toward the south and southwest, its age in these directions becomes younger and younger, and at the extreme limits of its extension it may even be younger than any true Devonian, and be contemporaneous with the basal member of the Mississippian.

While these monotonous black shale conditions obtained in the south, a series of waves of faunal immigration were penetrating the northeastern portion of the province. In the Portage of western New York occurs the Intumescens fauna[2] characterized by its numerous goniatites of the type of *Manticoceras intumescens*. This fauna, like the Cuboides fauna of the Tully limestone, is of European origin. The path of its migration into New York is believed by Clarke to have been the same as that of the earlier fauna, by way of the Interior Continental Province, but Ulrich and Schuchert[3] express the opinion that it came in from the Atlantic basin by an eastern route. Following the Intumescens fauna, in the same general region, is a fauna in the High Point sandstone, at the extreme summit of the Portage group, characterized by *Pugnax* of the type of *P. pugnus*, which is another European immigrant, and which has many species in common with the Lime Creek shales of the Interior Continental Province in Iowa. Succeeding the High Point fauna is the typical Chemung fauna with *Spirifer disjunctus* and its associates, which again are European immigrants, but are associated with other forms which are of Hamilton derivation.

[1] For a summation of the opinions which have been held in regard to the age of the black shale, see Girty, *Am. Jour. Sci.* (3), VI, 385, 386.

[2] Clarke, "The Naples Fauna in Western New York," *Sixteenth Ann. Rep. New York State Geol.*, 1896, pp. 31–161; also *Mem. N. Y. State Mus.*, No. 6.

[3] *Loc. cit.*

In central New York the history is somewhat different in that the Intumescens fauna does not penetrate there in its typical expression, and the Ithaca beds, which are equivalent to the Portage, carry a fauna which is in large part a Hamilton derivative, this being followed by the Chemung fauna. Still farther east, in the same state, the Portage epoch is represented by the non-marine Oneonta sandstone which is followed by marine beds with a recurrent fauna, which pass upward into the Chemung. In the extreme eastern portion of New York the non-marine Catskill conditions were doubtless constant from the beginning of the Upper Devonian until its close.

THE INTERIOR CONTINENTAL PROVINCE

Middle and Upper Devonian of the Interior Continental Province.—In passing from the Eastern Continental to the Interior Continental provinces, both the stratigraphic and faunal conditions are found to be totally different in almost every detail. In New York, where the Middle and Upper Devonian beds of the Eastern Continental Province have their most typical development, a maximum thickness of more than 3,000 feet of strata is recognized, and in the Appalachians in Pennsylvania the thickness is much greater, but in Iowa the total thickness of the Devonian beds of the Interior Continental Province is less than 300 feet. The entire series of Devonian beds in Iowa are commonly referred to the Middle and Upper Devonian, the Upper beds being unconformable upon the Middle,[1] but the limits of these divisions do not correspond at all with the limits of the Middle and Upper divisions of the Devonian in the Eastern Continental Province.

In the Middle Devonian of the Iowa geologists two major divisions are recognized, the Wapsipinicon and the Cedar Valley. Both the Wapsipinicon and the Cedar Valley are made up of minor formational units of more or less local development, and of these the Independence shales occupy a position near the base of the Wapsipinicon. The fauna of the Independence shales is the oldest of the Devonian faunas of Iowa,[2] and it shows much in common with the fauna of the Lime Creek shale of the Upper Devonian of the same state.

In the Upper Devonian three formations are included in Iowa, the Lime Creek shales, the State Quarry beds, and the Sweetland Creek

[1] Calvin, *Jour. Geol.*, XIV, 575; also *Ia. Geol. Surv.*, XVII, 197.

[2] Calvin, *Bull. U. S. Geol. Surv. Terr.*, IV, 725.

shale. As regards the relations of these three formations Calvin says:[1] "The three units referred to the Upper Devonian—the Sweetland Creek shales, Lime Creek shales, and State Quarry limestone—do not lie one above the other, but each is locally developed and lies unconformably on the Cedar Valley limestones."

The lower beds of the Wapsipinicon stage, other than the Independence shale, do not furnish any considerable fauna, *Martinia subumbona* being the most conspicuous species, but the higher beds, as well as the succeeding Cedar Valley beds, are abundantly fossiliferous, and faunally the dividing-line between the Wapsipinicon and Cedar Valley stages presents no more conspicuous break than that between the successive beds included within the Cedar Valley.

In correlating these faunas of the Iowan Devonian with those of the Eastern Continental Province, difficulty is met with because of the few points of contact between the two faunas. The faunas in the two provinces are so distinctly different that we are forced to the conclusion that there could have been no free communication between the two regions, but that they must have been entirely separated during the whole or the greater part of Middle Devonian time by some barrier, probably a land mass. During Upper Devonian time there was much more in common between the Iowan and New York faunas, showing that communication had been established ere that time. In the correlation of the faunas in the two provinces the important point to determine is the time of the establishment of this communication. Williams[2] has shown that the Cuboides fauna of the Tully limestone in New York is a distinct immigrant fauna from the Eurasian province, probably by way of the Mackenzie Valley and Iowa. The characteristic species of this fauna is *Hypothyris cuboides*, a species which is represented in the Iowan faunas by *Rhynchonella intermedia* Barris, the Iowan form apparently being specifically identical with the New York species. In Iowa this species is limited in its range to the upper portion of the Wapsipinicon stage, where it is highly characteristic of one of the divisions of the Fayette breccia,[3] and where it is associated with *Gypidula comis*. Because of the limited range of this species in

[1] *Jour. Geol.*, XIV, 575; also *Ia. Geol. Surv.*, XVII, 197.

[2] *Bull. G. S. A.*, I, 481–500.

[3] Norton, *Iowa Geol. Rep.*, IV, 160.

these Iowan beds, it seems safe to conclude that these higher Wapsipinicon beds are essentially equivalent in time with the Tully limestone of New York. Furthermore, almost the only fossil species in the lower Wapsipinicon beds is *Martinia subumbona*, which also is a common Tully limestone species.

Another point of contact between the faunas of the Iowan and the New York provinces is found in the faunas of the Lime Creek shales of Iowa and the High Point sandstone near Naples, N. Y. The High Point bed lies at the extreme top of the Portage in the New York section, and in a total fauna of 26 species, 14 are also present in the Lime Creek beds of Iowa.[1] This large proportion of identical species may be considered as a sufficient basis for the essential correlation of the beds.

If these two correlations are correct, a basis is established for the correlation of the entire Devonian series of Iowa, the Wapsipinicon being, in the main, the time equivalent of the later Hamilton of the New York section, its termination being essentially contemporaneous with the Tully limestone, the Cedar Valley being contemporaneous with the Portage group of New York, and the Lime Creek being contemporaneous with the closing stages of the Portage and the opening of the Chemung. There is no evidence whatever of the presence of any beds of Onondaga age in Iowa.

The invertebrate faunas of the so-called Upper Devonian formations of Iowa are less prolific than those of the Cedar Valley beds. The Lime Creek fauna includes a number of forms which are recurrent from the Independence shales near the base of the Wapsipinicon, a distribution which suggests the unity of the entire Devonian fauna of Iowa, and, further, that the Lime Creek is not far removed from the subjacent beds although there is apparently an unconformity between them. The State Quarry beds contain a number of distinctly Devonian brachiopods, among which may be mentioned *Pugnax alta* which also occurs in the Lime Creek shales, but the most conspicuous feature consists of the fish remains, *Ptyctodus calceolus* being the most abundant form. In the Sweetland Creek shales invertebrates are few in number, a species of *Spathiocaris* being perhaps the most common, a species which also occurs in the New Albany black shale of southern

[1] Clarke, *Bull. U. S. G. S.*, No. 16, p. 75.

Illinois and Indiana, as well as in a basal Kinderhook shale in Missouri. At the base of the formation a thin band occurs which is frequently crowded with the teeth of *Ptyctodus calceolus*, the same species which is present in the State Quarry beds and one which also has a wide distribution at the very base of the Kinderhook formations.

Following the Devonian of the Interior Continental Province to the northwest, it is next well exposed in Manitoba, and has been well described by Tyrrell.[1] Approximately 510 feet of strata are recognized, the lower 100 feet not having afforded any fauna. The beds referred to the Middle Devonian (Winnipegosan) are characterized by the presence of *Gypidula comis* throughout, and by *Stringocephalus burtoni* in the upper portion. The last of these species does not occur in Iowa, but *Gypidula comis* is an abundant and characteristic member of the fauna of the upper beds of the Wapsipinicon stage, where it is associated with *Rhynchonella intermedia* Barris (*Hypothyris cuboides*). In western Europe *Stringocephalus burtoni* is the index fossil of the Stringocephalus limestone at the summit of the Middle Devonian, and occurs immediately beneath the Cuboides zone. The Devonian beds superjacent to the Stringocephalus beds in Manitoba have been referred to the Upper Devonian by the Canadian geologists, a correlation which is doubtless correct, since the faunal succession is similar to that in Europe, where *Stringocephalus burtoni* marks a distinct horizon at the summit of the Middle Devonian.

The Devonian fauna of the Mackenzie basin has been described by Whiteaves[2] and has been correlated with the Cuboides zone of Europe and New York, a correlation which seems to be based on substantial evidence. Seventy-six forms are specifically identified, twenty-nine of which are either present or are represented by close relatives in the European faunas of similar age, while twenty-two are identified with American Hamilton species, ten with Iowan and seven with Chemung forms. In the Mackenzie basin the Stringocephalus zone has not been so clearly recognized as in Manitoba, although it is indicated in at least one locality. The entire Devonian section in the Mackenzie Basin consists of 2,800 feet of strata, but a considerable part of the lower portion may be of greater age, and the entire fauna is

[1] *Geol. Surv. Canada, Ann. Rep.*, V, (N. S.), Pt. I, pp. 204–9 E.

[2] *Cont. Can. Pal.*, I, 197–253, pls. 27–32.

known from 200 feet of beds between 300 and 500 feet below the summit of the entire series.

JUNCTION OF THE EASTERN CONTINENTAL AND INTERIOR CONTINENTAL PROVINCES

As has been indicated in the previous discussion of the faunas of the Eastern Continental and Interior Continental Provinces, the time of the establishment of a path of communication between the two was at the very opening of the Upper Devonian, when the Cuboides fauna found its way into the East, but the relations of the Iowan faunas with those of the East is not such as to suggest an entirely unobstructed intermingling of faunas even after this communication was finally established. Schuchert has suggested in his paleogeographic maps[1] that this communication was by way of a narrow and somewhat tortuous strait, the "Traverse Strait," which passed from southeastern Iowa in a general northeasterly direction, across Illinois through the Lake Michigan basin to northern Michigan. Within the limits of this strait occur the Devonian beds near Milwaukee, Wis., and those of the Grand Traverse region of Michigan, where there is a greater commingling of eastern and western forms than elsewhere, as might be expected under the circumstances. The waters of this strait were separated from those of the Eastern Continental basin by the comparatively narrow Kankakee peninsula.

THE WESTERN CONTINENTAL PROVINCE

The Devonian strata of the Western Continental Province occur at various localities in the Great Basin region, and their faunas have been described by Walcott in his *Paleontology of the Eureka District*.[2] One hundred and eighty specifically identified forms are recorded, of which 61 are new and 119 are identified with already known forms. The composition of the previously known portion of the fauna is as follows: 83 species are identical with forms from the Eastern Continental Province, including New York, Michigan, and the Ohio Valley, the other 36 being known from Iowa and other parts of the Interior Continental Province. Of the eastern species 29 are found only in the Onondaga fauna, 21 only in the Hamilton, and 13 only in Devonian

[1] *Am. Geol.*, XXXII, Pl. 21; also, *Ia. Geol. Surv.*, XVIII, pl. 16.

[2] *Monograph*, U. S. G. S., Vol. VIII.

beds younger than the Hamilton; the remaining species are common to the Onondaga and the Hamilton, with one exception, which occurs in the Hamilton and the Chemung. From these figures it is evident that this Great Basin fauna contains a strong Onondaga element, 48 species in all. Of the Hamilton species neither *Tropidoleptus carinatus*,[1] *Chonetes coronatus*, nor any of the strictly foreign species in the fauna are recognized, the entire Hamilton element being of that association which seems to have originated from the Onondaga. Of the three highly characteristic elements of the Onondaga fauna of the East, corals, cephalopods, and fishes, we find 11 species of corals and 11 species of cephalopods, but none of the latter are identical with those of the East, although they are congeneric. Of icthyc remains but a single tooth was collected by Walcott, but in the Kanab Cañon of northern Arizona a strongly marked Devonian fish horizon is recorded,[2] although the composition of the fauna has not been made known.

In its entirety the Devonian fauna of the Western Continental Province may be said to be composed of a combination of two distinct elements: (1) the Middle Devonian fauna of the Eastern Continental Province, exclusive of the southern hemisphere element in the Hamilton, and (2) the fauna of the Interior Continental Province. These two elements are not fully differentiated in the faunas, since species from the Iowan or Mackenzie Basin faunas occur indiscriminately in either the lower, middle or upper divisions of the Great Basin Devonian. The Onondaga element also occurs through all of the divisions, although it is most conspicuous in the lower beds. Within this province there is no faunal evidence indicating the presence of Devonian rocks of greater age than the Onondaga, but sediments were doubtless deposited in the area contemporaneously with the Onondaga, Hamilton, and Upper Devonian of the Eastern Continental Province, but no beds can be correlated definitely with either of the eastern formations. The older of the beds are doubtless of greater age than the oldest Devonian beds of Iowa, although they may not be older than some of those of the Mackenzie Valley.

[1] *Tropidoleptus carinatus* has been recorded from the Pinon Range, Nevada, but the species has not been figured, and the identification has not been confirmed, *Monograph*, U. S. G. S., VIII, 276.

[2] Walcott, *Monograph*, U. S. G. S., VIII, 7; also *Am. Jour. Sci.* (3), XX, 225.

The path of communication between the Eastern Continental Province, in Onondaga time, and the Western Continental Province must have been indirect, although there was certainly some community of origin of the faunas in the two regions. If the northern origin of the Onondaga fauna, as has been suggested by the writer,[1] has sufficient foundation, which is perhaps doubtful, the fauna may have migrated southward into two epicontinental embayments, one into the Eastern Continental Province, by way of Hudson Bay and James Bay, and another farther west into the Western Continental Province. The mingling of the Onondaga and the Iowan faunas might be accounted for on this basis, since it is quite definitely recognized that the latter fauna has a northwestern origin, at least in so far as North America is concerned. One objection to this view is the fact that the Onondaga fauna is not represented among the known faunas from the Mackenzie Basin, although there is sufficient room for its occurrence in some of the older Devonian beds of that region which have not yet afforded any fauna. A southern pathway of communication between the two provinces is a possibility, although on such an hypothesis the absence of the southern hemisphere element of the later Middle Devonian faunas of the East is not easy to account for.

THE NORTH AMERICAN MISSISSIPPIAN PROVINCES

The early stages of the Mississippian period were marked by a continuation of the transgression of the sea in the south and southwestern part of the Eastern Continental Province, which had been initiated during Upper Devonian time, but it was extended also to the northwest. Before the close of the Kinderhook epoch, the sea had crossed the Kankakee peninsula and had surrounded the Ozark land which became an island or was perhaps entirely submerged, and had stretched away toward the Rocky Mountain land, so that the earlier Eastern Continental and Interior Continental provinces were merged into one great interior province with three subordinate basins or subprovinces, (1) the Appalachain Basin lying between Appalachia and the Cincinnati arch and extending from Michigan to Alabama, (2) the Mississippi Valley basin extending westward from the Cincinnati arch and merging with the Appalachian Basin to the south, (3)

[1] *Jour. Geol.*, X, 429.

the Rocky Mountain Basin. The Western Continental Province remained much as in Devonian time, faunally isolated to a great extent from the interior province. The Eastern Border Province was even more isolated, its faunal history, so far as known, having no points of contact with the interior.

The more complete and differentiated faunal history of the Mississippian is that of the Mississippi Valley Basin which will be used as a standard of comparison for the other provinces or subprovinces considered.

THE MISSISSIPPI VALLEY BASIN

The Southern Kinderhook fauna.—When the Upper Devonian or New Albany black shale is well developed in southern Indiana and Illinois, the initial Kinderhook bed, the Rockford limestone, follows it with no stratigraphic break. In following the Kinderhook beds to the north, however, they are found to succeed, unconformably, formations of much greater age. The same condition also probably holds in passing from Burlington, Ia., to the south, although the transition beds from the Devonian to the Kinderhook are not exposed in the Burlington section. An actual land barrier, the Kankakee axis of Schuchert, separated these northern and southern basins at the beginning of Kinderhook time, when each basin was occupied by its own distinctive and characteristic fauna. Before the close of the Kinderhook this barrier was submerged and a common fauna occupied the entire Mississippi Valley Basin.

The fauna of the Rockford limestone contains new elements which were unknown in the preceding Devonian faunas, associated with certain other forms which are clearly Devonian derivatives. The typical expression of this more southern type of the Kinderhook fauna, however, is found in the Chouteau limestone of central and southern Missouri and Illinois, although there are several modifications of the fauna in the various more or less local formational units of the Kinderhook of this region. Among other things the fauna contains numerous goniatites, some of which are notable forms and have no relationships with any of our known Devonian goniatites. *Aganides rotatorius*, from the Rockford goniatite bed of Indiana, is identical with a form in the basal Mississippian beds of Belgium and Ireland. Associated

with this form at Rockford is *Prodromites gorbyi* which occurs also in the Chouteau limestone of central Missouri. This latter goniatite is the most advanced one of the Mississippian faunas, having, as it does, a secondarily lobed suture such as, at no very distant period in the past, was considered to be characteristically Mesozoic in type. Another peculiar cephalopod in the fauna is *Tribloceras digonum* which occurs in the fauna at various localities. A peculiar type of pelecypod is found in the genus *Promacrus*, which occurs also in the early Mississippian beds of Belgium. These and many other forms in the fauna characterize it as something distinctly younger than any Devonian fauna, with numerous bonds of affinity uniting it with the higher and more typical Mississippian faunas. However, there occur associated with these characteristic portions of the fauna certain species, especially among the pelecypods, which are clearly Devonian derivatives, and, strange to say, their relationships are usually with members of the Hamilton fauna, rather than with the higher Devonian faunas of the Eastern Continental Province. The Hamilton relationships of the fauna are perhaps best seen in the fauna of the Glen Park limestone,[1] where the pelecypods and gastropods are all close allies of Hamilton forms, and where one form even seems to be specifically identical, but associated with these is a member of the highly characteristic Mississipian genus *Syringothyris*.[2]

The origin of this southern Kinderhook or Chouteau fauna is believed to have been in the Atlantic Basin, where Middle Devonian faunas of Hamilton type had probably retreated as the Upper Devonian immigrants became established in the Eastern Continental Province, or where they had persisted during Upper Devonian time, having never been encroached upon by the immigrants. During the long lapse of time most of the species had been modified, and there had been absorbed into the fauna a new element from some unknown region. The return of this fauna into the Mississippi Valley Basin marks the opening of the Kinderhook epoch and the Mississippian period.

[1] Weller, *Trans. St. Louis Acad. Sci.*, XVI, 435–71.

[2] The species described in the *Fauna of the Glen Park Limestone* (*loc. cit*). as *Spirifer jeffersonensis*, has since been definitely identified as a member of the genus *Syringothyris*.

The Northern Kinderhook fauna.—North and west of the Kankakee peninsula, in the eastern portion of the Devonian Interior Continental Province, the earliest Mississippian faunas were as distinctly different from those of the southern portion of the Eastern Continental Province, as had been the preceding Devonian faunas. The oldest of these northern Kinderhook faunas is that of the Chonopectus sandstone[1] at Burlington, Ia., and elsewhere in Iowa and Illinois. This fauna contains a large Devonian derivative element, especially among the pelecypods, but its relationships are with the Chemung faunas of the Upper Devonian, and are totally different from the Devonian derivatives of the southern fauna. Another modification of the northern Kinderhook fauna is found in the Louisiana limestone, which is believed to be in part contemporaneous with, and in part younger than, the Chonopectus fauna. One of the most characteristic members of this northern Kinderhook fauna is the striated rhynchonelloid genus *Paraphorhynchus* which occurs also in the early Mississippian faunas of northwestern Pennsylvania.

In the Burlington, Ia., section the Chonopectus fauna occurs at the summit of a series of shales, becoming arenaceous above where the fauna occurs, which have a total depth of 160 feet. The lower 100 feet of the formation lies beneath the level of the Mississippi River, so that the contact with the underlying formation and the age of the subjacent bed is not known. This lower bed, however, is probably Devonian, and is not unlikely the Cedar Valley limestone, since that formation lies unconformably beneath the Kinderhook beds farther south in Calhoun County, Ill. If this is the case then these lower shales of the Kinderhook correspond in position with the Sweetland Creek shales of the Upper Devonian in Muscatine County, Ia. There is, however, perhaps insufficient faunal evidence upon which to base a definite correlation of these two shale formations. The most conspicuous faunal character of the Sweetland Creek beds is the presence of numerous *Ptyctodus* teeth in the basal bed, occupying a few inches above the unconformity. A similar *Ptyctodus* bed occurs not infrequently at the base of the Kinderhook in both the northern and southern provinces. Such is the case at the base of the Louisiana limestone at Louisiana, Mo., where *Ptyctodus* occurs abundantly in a thin shale

[1] Weller, *Trans. St. Louis Acad. Sci.*, X, 57–129; also *Jour. Geol.*, XIII, 617–34.

bed beneath the limestone. In southeastern Missouri a one-foot bed of sandstone occurs at the base of the Kinderhook with numerous phosphatic nodules and some worn *Ptyctodus* teeth. In southwestern Missouri a thin formation at the base of the Kinderhook has been described by Shepard[1] as the Phelps sandstone, in which *Ptyctodus* teeth are abundant, and the same conditions obtain at Providence,[2] in central Missouri. In all of these localities the same species, *Ptyctodus calceolus* N. and W., seems to be the usual form. Occupying, as these *Ptyctodus* beds do, a position immediately superjacent to a more or less profound unconformity, it is not likely that it is strictly contemporaneous in all of these localities, but that they are all associated with one general geologic movement, and are contemporaneous within comparatively narrow limits, is quite certain. The presence of the remains of this fish fauna, in both the southern and northern Kinderhook provinces, while the invertebrate faunas are so distinct, is doubtless due to the fact of the greater mobility of the fishes, and their greater powers of adaptation to certain changing conditions. Besides these fish remains, the most common fossil in the Sweetland Creek beds is a crustacean belonging to the genus *Spathiocaris*, which also occurs in the Upper Devonian black shale in southern Indiana and Illinois, and in a basal Kinderhook shale in southwestern Missouri. This crustacean, like some of the Lingulas, seems to be associated rather with a peculiar type of sediment than with a definite time period of narrow limits. Neither the *Ptyctodus* nor the *Spathiocaris* have been found in the basal Kinderhook shales at Burlington, but the fauna of the basal portion of the formation is of course not known.

During the progress of Kinderhook time the sea was encroaching from both the north and the south, until before the close of the epoch free communication was established between the earlier separated provinces and the fauna of the southern province became the dominant type throughout the entire Mississippi Valley Basin. This northern incursion of the southern fauna is well exhibited in the uppermost 15 feet of the Kinderhook section at Burlington and elsewhere.

From the outline of the faunal history here given, it is evident that the arrangement of the Kinderhook formations into three successive

[1] *Mo. Geol. Surv.*, XII, 77.

[2] "Bed No. 4, Stewart," *Kansas Univ. Quart.*, IV, 161.

divisions, the Louisiana, Hannibal, and Chouteau, as has usually been done, does not express the proper relationships of the faunas. The Chouteau fauna, in some of its expressions, is without doubt as old as the Louisiana fauna, and it is as impracticable to make one continuous section to contain all of the Kinderhook formations, as it would be to make a standard Devonian section to include the formations of New York and Iowa.

Early Mississippian faunas of the Appalachian Basin.—In the waters between the Cincinnati arch and the old Appalachian land in early Mississippian time, the faunal conditions were more like those of the southern Kinderhook province than the northern. In the Bedford shale of that basin a fauna occurs which is largely of Devonian derived species, and like the southern Kinderhook faunas these species have their relationships with Hamilton rather than with Upper Devonian forms. The succeeding formations in Ohio constitute the several members of the Waverly group with faunas showing more or less close relations with those of the southern Kinderhook. In the northern part of the basin, as in the Waverly beds of northwestern Pennsylvania, the presence of such forms as *Paraphorhynchus*[1] suggest relationships with the northern Kinderhook faunas of the Mississippi Valley, a relationship which might have been established by faunal migration from the West to the East by way of the Traverse Strait and Michigan.

Post-Kinderhook faunas of the Mississippi Valley Basin.—With the submergence of the Kankakee Peninsula and the partial or complete submergence of the Ozark land, the source of the clastic sediments in the immediate Mississippi Valley region was removed, and a great period of limestone formation was initiated which is best exemplified in the Burlington and Keokuk formations. The fauna of this clear sea was in large part an outgrowth of the later Kinderhook faunas, and is best characterized by the wonderfully rich crinoidal element.

The fauna of the formations which together constitute the Osage division of the Mississippian is in some respects unique. The great crinoidal element is in large part or wholly indigenous to this province,

[1] *Rhynchonella medialis* and *R. striata* Simpson (*Trans. Am. Phil. Soc.*, XV, 144), from Warren County, Pa., are members of this genus.

although it had its beginnings in the preceding Kinderhook. No locality in the world, so far as known, has furnished so large a number of crinoids of similar age, either in genera, species, or individuals, as this Mississippian province. The fauna, in its entirety, exhibits much in common with the mountain limestone of England, Ireland, and elsewhere in Europe. Many species of brachiopods in the formations either are identical or are so closely allied as to be difficult of separation, and the correlation of the Osage with the Mountain Limestone of England, or at least of some part of it, is based upon substantial evidence. Evidence sustaining the indigenous character of the crinoidal element in the fauna is found in a comparison of these forms from the Osage of the Mississippi Basin and from the Mountain Limestone of Europe. Every genus in the Mountain Limestone occurs also in the American faunas, while there are many genera which do not occur outside of the Mississippi Basin; furthermore, all of those genera which occur in both this Mississippian province and in Europe are represented by a larger number of species in America. These facts seem to indicate that the Mississippi Valley Basin was the metropolis for this great crinoidal fauna.

During this period the Cincinnati arch was above sea level, and from this island clastic sediments were being deposited off its western and southwestern shore, which constitute, in part at least, the Knobstone formations of Indiana and Kentucky, although the basal portion of the Knobstone is undoubtedly of Kinderhook age. The faunas associated with these clastic sediments are usually more meager than in the calcareous sediments of the clear seas farther west, and are somewhat different in character; however, they possess much in common as is evidenced by the wonderfully prolific crinoid fauna of the Crawfordsville beds in Indiana.

The later phases of the Osage sedimentation became more clastic, especially toward the north, doubtless because of the elevation of the land to the north, and in the Keokuk formation numerous shaly layers occur, intercalated between limestone beds. The shales become more and more dominant until, in the Warsaw formation, shales constitute the major portion of the sedimentation. In the southern portion of the Mississippian Basin this change in sedimentation was less or even not at all effective, since the Warsaw, as a distinct shale

horizon, is scarcely or not at all recognizable beyond a short distance south of St. Louis. The fauna of these shaly Warsaw beds is more or less closely allied to that of the subjacent formations, but it contains numerous species which are quite distinct and some which are either identical with, or related to, members of the superjacent faunas.

Subsequent to the Warsaw sedimentation the land to the north of the Mississippi Valley Basin was elevated. The Salem limestone which lies immediately above the Warsaw has a thickness of only 8 or 10 feet at Warsaw, Ill.,[1] where the formation consists of an impure, arenaceous limestone. To the south it increases in thickness to a maximum of about 100 feet, and is for the most part a very pure limestone, although magnesian layers are not unusual. The formation extends eastward beneath the younger formations, and is again exposed in western Indiana, off the western shore of the old Cincinnati island. A notable feature of the formation is the presence in it, throughout its entire geographical extent, of more or less extensive oölitic beds.

The fauna of the Salem limestone, commonly known as the Spergen Hill fauna, contains many diminutive forms, one of the most common species being *Cliothyris hirsuta*, which was present in a Kinderhook oölite at Burlington, Ia. Several small forms of *Conocardium* are also common in the fauna, one of the species, *C. meekana*, being somewhat closely allied to *C. pulchellum* from the same Kinderhook oölite. A comparison of the fauna with the Mississippian faunas of other parts of North America indicates a close relationship with certain faunas far to the northwest in Montana and Idaho. Meek[2] has recorded a fauna from a limestone in Idaho in which nearly one-half of the forms are identical with Spergen Hill species, and in the Yakinikak limestone[3] in northwestern Montana a similar fauna also occurs. These limestones in Montana and Idaho are doubtless to be associated with the Madison limestone of the Yellowstone National Park, in which occurs a fauna having relationships with the Kinderhook of the Mississippi Valley, and especially with that of the Kinderhook oölite bed at Burlington, Ia., a relationship which may account for the partial recurrence in

[1] *Ill. State Geol. Surv., Bull. No.* 8, p. 90.

[2] *Am. Jour. Sci.* (3), V, 383.

[3] *Bull. Geol. Soc. Am.*, XIII, 324.

the Salem limestone of a fauna which has some features in common with this earlier fauna of a similar earlier oölitic bed.

Superjacent to the Salem is the St. Louis limestone which attains a maximum thickness of 250 feet, but in the northern portion of the Mississippian province it is reduced in thickness and lies unconformably upon the Salem, this unconformity being well shown near Warsaw, Ill. This unconformity indicates that the Mississippian sea retreated to the south during late Salem time, and readvanced in early St. Louis time. The retreat did not reach as far as Alton, Ill., however, as near that city the succession is perfectly conformable. The lowermost bed of the St. Louis in the north is a conspicuous limestone breccia which may be a northward continuation of a brecciated horizon near the middle of the formation in the region about St. Louis and Alton, but in following the formation to the south this brecciated horizon becomes less conspicuous and disappears. The fauna of the St. Louis is on the whole a meager one, and is quite different from that of the Salem. In some respects it suggests a recurrence of the Osage fauna, although the species are essentially all different, and some forms, of which the coral *Lithostrotion canadense* is perhaps the most notable, are distinctly new elements in the fauna.

The St. Louis is followed conformably by the Ste. Genevieve limestone. This formation differs from the St. Louis and resembles the Salem in the presence of oölitic beds, and with the recurrence of these conditions favorable for the formation of oölitic limestone, there is also a recurrence of the Salem fauna. Many species of the Ste. Genevieve are identical with those in the Salem, although the fauna contains species also which are characteristic to it. Among the latter a conspicuous one near Alton and in Monroe County, Ill., is *Pugnax ottumwa*, this species being present to the exclusion of all others in some localities. The abundance of the same species in the Pella beds of Iowa, the highest division of the so-called St. Louis of that state, suggests the correlation of these beds with the Ste. Genevieve rather than with any part of the St. Louis proper. This occurrence in Iowa is in accord with conditions elsewhere which indicate that the Ste. Genevieve was a time of great expansion of the Mississippian sea in all directions. It was at this time only, during the entire Mississippian period, that limestone conditions obtained in the northern part of the

more or less inclosed Appalachian Basin east of the Cincinnati island, where the Maxville limestone represents the Ste. Genevieve formation of the Mississippi Valley. To the southwest, in northern Arkansas, the Spring Creek limestone, a formation which, with the Batesville sandstone, is essentially contemporaneous with the Ste. Genevieve, and probably uncomformable upon the subjacent Osage beds, carries a most remarkable fauna with peculiar immigrant forms from the far southwest,[1] a faunal character which indicates that the Mississippian sea reached so far in that direction as to communicate with the Western Continental Province, where these peculiar forms had existed, some of them having persisted from Devonian time.

Subsequent to the great extension of the sea during Ste. Genevieve time the northern portion of the Mississippi Valley Basin became dry land, and so remained until it was reoccupied by the sea in Pennsylvanian time, with only a partial readvance in early Chester time. In the extreme southern portion of Illinois and in Kentucky, Ulrich[2] has recognized three members in the Ste. Genevieve formation, the Fredonia, the Rosiclare, and the Ohara, but in all the region north of Chester, Ill., the upper portion is wanting and the superjacent Cypress sandstone rests unconformably upon the lower beds of the Ste. Genevieve. The higher beds of the Ste. Genevieve in the extreme southern Illinois, especially the Ohara beds of Ulrich, bear a fauna which has much in common with the faunas of the Chester above the Cypress sandstone, but even here there is possibly an unconformity between these beds and the Cypress.

The Cypress sandstone initiates the Chester, the closing epoch of the Mississippian in the typical portion of the Mississippi Valley Basin, during which period the conditions of sedimentation were continually shifting, there being interbedded limestone, shale, and sandstone formations, the limestone and shale predominating below, above the initial Cypress sandstone, and the sandstones being more conspicuous above. No remnant of these beds is preserved, so far as known, north of a point some miles south of St. Louis, although it is possible that the Chester sea extended further north than this. It is quite certain, however, that this sea never had the great extent to the

[1] Williams, *Am. Jour. Sci.* (3), XLIX, 94–101.

[2] *Professional Paper*, U. S. G. S., No. 36, p. 38.

north which had obtained during some of the earlier Mississippian periods.

The faunas of the Chester beds have a certain individuality of their own, although the successive limestone beds, in which the fossils mostly occur, have not yet been faunally differentiated with any great success. A conspicuous feature of the fauna is the presence of numerous blastoids of the genus *Pentremites*, and bryozoans, especially of the genus *Archimedes*. Among the brachiopods, especially, there is some recurrence of species identical with, or closely allied to, forms in the Salem and Ste. Genevieve limestones, but this characteristic is not limited alone to the brachiopods.

In the typical portion of the Mississippi Valley Basin the Mississippian period closes with the withdrawal of the Chester sea. Farther to the southwest, in Arkansas, however, toward the more open sea, it has been suggested by Ulrich[1] that similar faunas persisted into beds which are really of Pennsylvanian age, under which interpretation the line between the Mississippian and the Pennsylvanian, in that region, would be somewhat arbitrarily drawn. It is not improbable that the Arkansas beds are younger than any in the Mississippi Valley, yet that fact should not necessarily be considered as sufficient basis for referring them to the Pennsylvanian. The time boundary between the two periods should be marked by the time of maximum withdrawal of the sea or the subsequent readvance during which new sets of conditions were introduced.

MISSISSIPPIAN FAUNAS OF THE APPALACHIAN BASIN[2]

During Mississippian time the Cincinnati arch constituted a barrier between the central Mississippian sea and the Appalachian basin, a gulf which lay between this island and Appalachia. Into this basin clastic sediments were being carried from the east, north, and west, so that the pure limestones of the Mississippi Valley are absent, and the faunas are neither so prolific nor so well differentiated. In this basin the Mississippian formations are included within the Pocono and Mauch Chunk formations of Leslie. The most definite point of faunal contact between this basin and the Mississippi Valley Basin is found in

[1] *Professional Paper*, U. S. G. S., No. 24, p. 109.

[2] For a detailed description of the stratigraphy and correlation of the Mississippian of the Appalachian Basin, see Stevenson, *Bull. Geol. Soc. Am.* XIV, 15–96.

the Maxville limestone, whose fauna is to be correlated essentially with the Ste. Genevieve of southern Illinois and Missouri. It has been shown by Stevenson[1] that only the upper portion of the Pocono is of Mississippian age, and that this part is stratigraphicaly continuous with the Waverly group of Ohio. The basal member of the Waverly group, in the more general application of that term, is the Bedford shale in which occurs a fauna with Hamilton affinities.[2] As has already been pointed out, this fauna is believed to be associated with the incursion of the Hamilton-like forms which constitute one element in the southern Kinderhook faunas. The composition of the succeeding Waverly faunas has been more carefully studied by Herrick[3] than by anyone else, and they exhibit throughout more or less affinity with the Kinderhook faunas of the Mississippi Valley Basin. Numerous members of the fauna suggest a Devonian derivation sometimes from Hamilton and sometimes from Chemung progenitors, as if they were to some extent a mingling of the two Kinderhook faunas of the Mississippi Valley. These Waverly faunas are, however, in no wise to be considered as contemporaneous with the Kinderhook alone of the Mississippi Valley, but they must also represent the Osage. In the Appalachian Basin, with its continuity of clastic sedimentation, environmental conditions similar to those of the Kinderhook persisted through Osage time, consequently there is no sharp differentiation of the faunas as there was in the Mississippi Valley where the period of clastic sedimentation was displaced by the clear seas in which nothing but calcareous sediments were deposited. For this reason the typical Burlington and Keokuk faunas do not occur in the Appalachian Basin, but an occasional member of these faunas found its way into the basin and such forms left records which are of value in the correlation of the faunas.

Outside of Ohio little or no detailed faunal study of these beds has been made, but Stevenson[4] has pointed out the stratigraphic correlation of the beds throughout the Appalachian Basin from Pennsylvania to Alabama.

[1] *Loc. cit.*

[2] Herrick, *Geol. Surv. Ohio,* VII, 507.

[3] A summary of Herrick's work is to be found in *Geol Surv. Ohio,* VII, 495–515.

[4] *Loc. cit.*

In the Mauch Chunk series of earlier authors, Stevenson[1] recognizes three members, a lower the Tuscumbia, a middle the Maxville, and an upper the Shenango. Toward the close of Pocono time there was a marked contraction of the sea in the Appalachian Basin, just as was the case at a corresponding time in the Mississippi Valley Basin. This contraction was of such proportions that the Tuscumbia beds were not deposited in Ohio in the area occupied by the earlier Waverly, except at the Kentucky border, but, as in the west, there was a readvance of the sea until it had reached its maximum extent in the deposition of the Maxville limestone which is to be correlated essentially with the Ste. Genevieve limestone of the Mississippi Valley. Such a correlation would make the Tuscumbia essentially contemporaneous with the St. Louis limestone of the Mississippi Valley, a correlation which is sustained by the paleontologic evidence. The Shenango is said to contain fossils characteristic of the Chester of the Mississippi Valley,[2] and may be correlated with that formation.

MISSISSIPPIAN FAUNAS OF THE ROCKY MOUNTAIN BASIN

In Montana and elsewhere in the northern Rocky Mountain region, limestones of Mississippian age are widely distributed, although but little data in regard to the faunas have been published. The most notable contribution to our knowledge of these faunas is that of Girty on the Carboniferous fossils of the Yellowstone National Park.[3] The faunas here described are distributed through more than 1,600 feet of strata of the Madison limestone, but they do not show any such differentiation as is recognized in the Mississippi Valley. One general fauna persists with but minor changes throughout the entire series and this fauna shows many affinities with the southern Kinderhook faunas of the Mississippi Valley, as well as with the fauna of the Salem limestone. Faunas allied to that of the Salem have also been detected elsewhere in the region, as the Idaho fauna noted by Meek and the fauna of the Yakinikak limestone already mentioned. These relations suggest that in this northwestern region a long-lived fauna, having more or less close relationships with the Salem fauna, was contemporaneous with the larger part of the entire Mississippian series of the

[1] *Op. cit.*, p. 85.

[2] Stevenson, *op. cit.*, p. 85.

[3] *Monograph*, U. S. G. S., XXXII, Pt. 2, pp. 479–599.

Mississippi Valley. At intervals this fauna made incursions into the Mississippi Valley Basin, as is evidenced by its representatives in the Kinderhook oölite at Burlington, Ia., in the Salem limestone, again in the Ste. Genevieve, and to some extent also in the Chester. That this is not a complete interpretation, however, is shown in the occurrence of a group of crinoids described by Miller and Gurley from near Bozeman, Mont.,[1] which strongly suggests the crinoid fauna of the lower Osage horizons of the Mississippi Valley. It is not improbable that when our knowledge of these faunas in the northwest is expanded, we may be able to recognize elements related to most or all of the faunal divisions of the Mississippi Valley. The evidence at present available suggests that this region occupied a distant part of the same sea which was present farther to the southeast, and that there was more or less unobstructed means of faunal communication between the two regions.

From the Lake Valley region in New Mexico, there has been described an early Mississippian fauna[2] which is a close ally of the fauna of the Fern Glen formation at the summit of the Kinderhook in the Mississippi River section south of St. Louis. This occurrence idicates that the Mississippian sea had transgressed at least as far to the southwest as New Mexico by the close of Kinderhook time, and that means for faunal communication was unobstructed in that direction.

The Mississippian faunas from Colorado have been described by Girty[3] who has reported on materials collected in nine separate regions from the Ouray, Leadville, and Millsap limestones. All of these faunas are separated into two groups by that author, both of which are considered to be of essentially the same age, early Mississippian, probably Kinderhook or early Osage. The composition of the fauna is strikingly like that of the Madison limestone of the Yellowstone National Park, its relationships being especially with the Chouteau of the Mississippi Valley Basin, but the presence of such forms as *Eumetria marcyi?*, *Straparollus cf. spergenensis*, *Fenestella serratula?*,

[1] *Bulletin*, Ill. St. Mus. Nat. Hist., No. 10. "*Poteriocrinus bozemanensis P. douglassi*, and *Platycrinus douglassi*;" *ibid.*, No. 12, "*Batocrinus douglassi*, *Rhodocrinus douglassi*, *R. bozemanensis*, *R. bridgerensis*, *Platycrinus bozemanensis*, *P. bridgerensis*, *Dichocrinus bozemanensis*."

[2] Miller, *Jour. Cin. Soc. Nat. Hist.*, IV, 306–15; also Springer, *Am. Jour. Sci.* (3), XXVII, 97–103.

[3] *Professional Paper*, U. S. G. S., No. 16.

etc., suggest also a relationship with the Salem limestone fauna of the Mississippi Valley. The conditions are therefore similar to those in the Madison limestone of the North, and the interpretation of the faunal relations in that region can doubtless be extended to the more southern area.

MISSISSIPPIAN FAUNAS OF THE WESTERN CONTINENTAL PROVINCE

For a knowledge of the Mississippian faunas of the Great Basin region we are especially indebted to Walcott, who has described them from the Eureka district of Nevada.[1] The faunas occur at various horizons through a series of "Lower Carboniferous" limestones 3,800 feet in thickness, and are most remarkable from the fact that there is a general mingling of forms which, if found in the Mississippi Valley, would be considered as characteristic either of the Devonian, the Mississippian, or the Pennsylvanian. There is, however, a notable absence of the more conspicuous elements of the Mississippian faunas of the Mississippi Valley, such as the crinoids of the Osage faunas, the large Spirifers of the *S. striatus* type, the *Archimedes* and *Pentremites* of the Chester faunas, etc. None of the specialized Mississippi Valley faunas can be recognized. This basin must have been isolated, during Mississippian time, both from the Mississippi Valley and from the Rocky Mountain basins. The one point of faunal contact between the Great Basin and the Mississippi Valley is found in the presence of several of the peculiar Great Basin forms in the fauna of the Spring Creek limestone of northern Arkansas, among which *Rhynchonella eurekensis* and *Leiorhynchus quadricostatus* are perhaps the most notable. The age of the Spring Creek limestone is believed to be very close to that of the Ste. Genevieve limestone, at which time, perhaps, the Mississippian Sea had its greatest extension in the East. With this expansion of the sea there would seem to have been established a brief communication with the Great Basin region, of such a nature as to allow a group of these peculiar forms to migrate at least as far east as northern Arkansas. It is apparently impossible to correlate this incursion in the Great Basin, however, perhaps because of our imperfect knowledge, because the most notable of the immigrant species, *R. eurekensis*, has a long range in the Great Basin beds.

[1] *Paleontology of the Eureka District*, Monog., U. S. G. S., Vol. VIII.

DISCUSSION

Professor Calvin

The paper presents very fairly and fully the taxonomic relations of the Devonian and the Mississippian so far as Iowa is concerned. I should be disposed to question the propriety of correlating the Sweetland Creek shales of Muscatine County with any part of the Kinderhook. It is true that in Missouri beds which have been referred to the Kinderhook furnish *Ptyctodus* and some other Devonian types; but at Burlington the Kinderhook shales carry a fauna that, in practically all its aspects, is Carboniferous. On the other hand, the fauna of the Sweetland Creek shales is characteristically Devonian. Leaving out *Ptyctodus*, which may belong to either of the two formations, all the other life forms will be found to be distinctively Devonian. The Sweetland Creek beds furnish two species of *Synthetodus*, a form very common in the State Quarry limestone. Now the State Quarry limestone is in large part made up of imperfectly comminuted shells of that most intensely non-Carboniferous of all the Devonian types, *Atrypa reticularis*, with occasional shells of another almost equally intensely Devonian form, *Gypidula comis*. Fossils are rather rare in the Sweetland Creek beds, but all that have been noted are such as to exclude this formation from any close relation to the Kinderhook.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

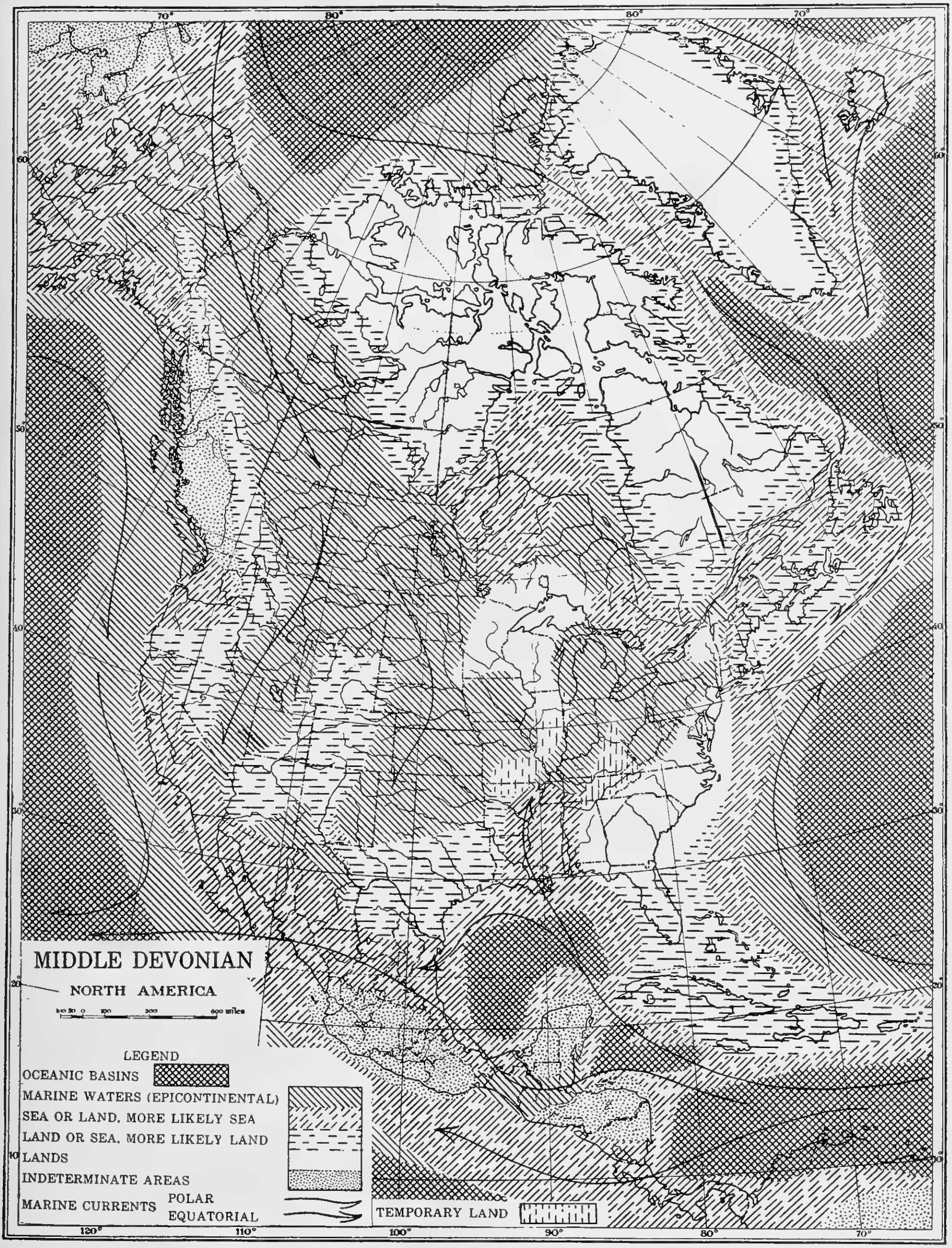
5. MIDDLE DEVONIAN NORTH AMERICA

The archipelagic condition of North America which began in the Ordovician persisted through the two succeeding periods with many changes of land and sea. Any refined study of these changes involves somewhat precise correlations which have already been carried far. The map here presented is of one passing phase only. The time represented is that before and after the invasion of the Hamilton fauna into the New York embayment, as is indicated by the temporary land barrier shown in Illinois and Missouri. The great thickness of sediments in the eastern Appalachian trough indicates marked orogenic movement during the middle and upper Devonian in the land lying toward the Atlantic. The southeastern expansion of the sea over Appalachia began apparently in middle Devonian and extended into upper Devonian time.

6. MISSISSIPPIAN NORTH AMERICA

The distribution and character of the Mississippian sediments leads to the inference that the time was one of an extended epicontinental sea with low and relatively limited lands. The archipelago of the immediately preceding period gave way to a general submergence of all the southwestern portion of the continent. In the far north conditions were favorable to the deposition of coal and other continental deposits associated with marine beds. The Atlantic and eastern portion of the interior sea and the wide sea covering all the western states present differences of habitat which are emphasized by Dr. Weller in his discussion. Toward the close of the Mississippian or early in Pennsylvanian time, an extensive land area emerged in the Colorado-New Mexico region, as indicated by erosion of the Mississippian sediments.

[1] Published by permission of the Director of the U. S. Geological Survey.


MIDDLE DEVONIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
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TEMPORARY LAND
120°
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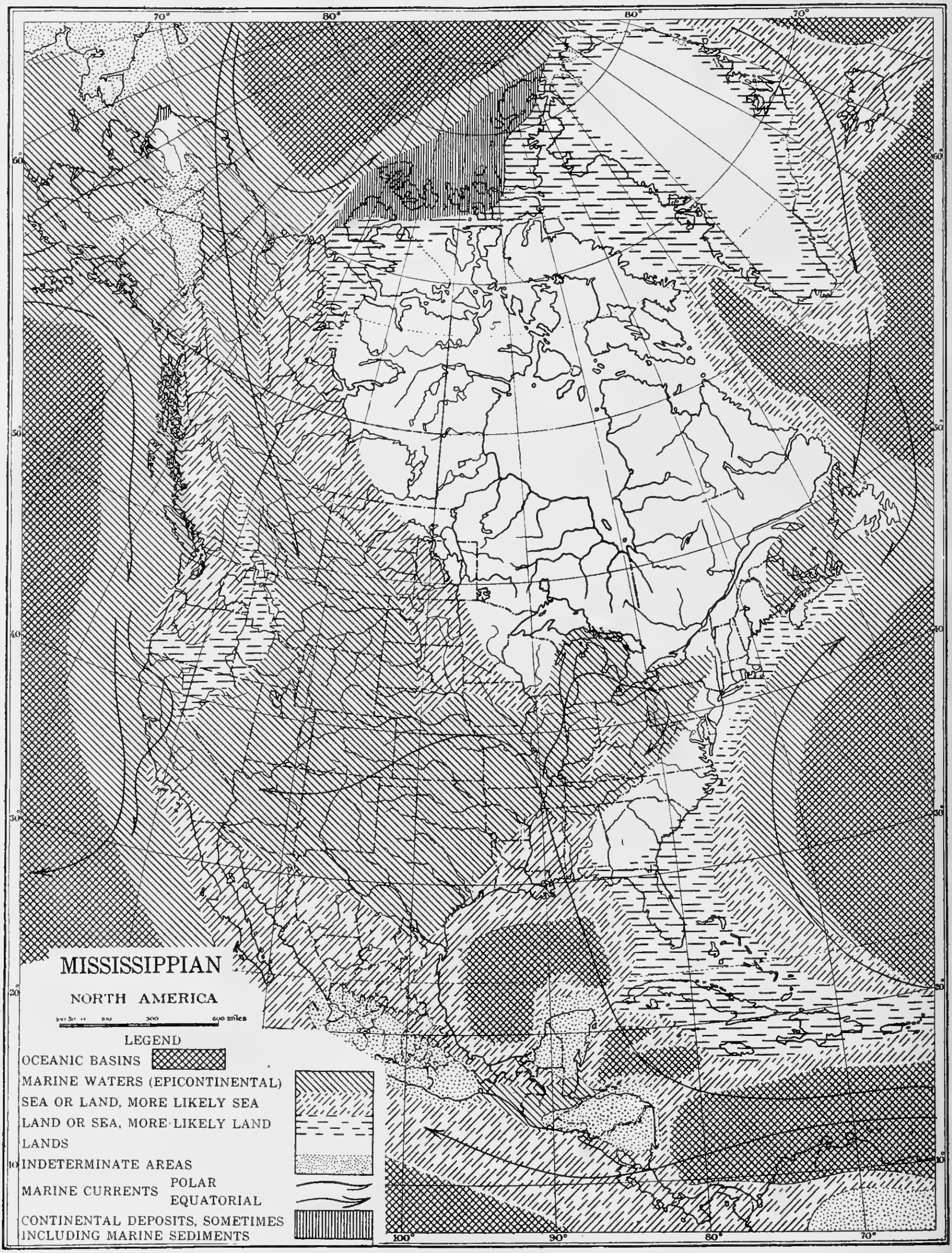
MISSISSIPPIAN
NORTH AMERICA
600 miles
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES
INCLUDING MARINE SEDIMENTS

THE VALUATION OF UNCONFORMITIES

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The utility of unconformities in geology has long been recognized, and the historical significance of such structures is becoming more and more clearly understood. In the early days of geologic science only the more clearly visible unconformities involving discordance of strata were identified as such. Later it was shown that an irregular eroded surface between parallel beds may imply much the same conditions and events as the more conspicuous unconformities, except that deformation of the older rocks is not involved. The distinction was clearly made by Irving, in his admirable paper on the correlation of unfossiliferous rocks; the breaks accentuated by discordance were called "true unconformities," while those in parallel strata were styled "erosion intervals."[1] It was felt that the very word "unconformity" involved the idea of angular discordance between the beds above and below, and hence that any interruption between parallel beds must go by another name. In spite of this, however, the scope of the term unconformity has been gradually extended so that we find Le Conte, writing in 1890, combining breaks between discordant beds and eroded surfaces in parallel strata as merely two varieties of unconformity.[2] This usage is the one now generally followed by geologists (although the phrase *erosion interval* is still current), and it is in this sense that the term will be employed in the ensuing pages.

We now have several types of unconformities clearly distinguished: (*a*) eroded surface separating parallel strata; (*b*) contact between rocks of wholly unlike origin (for example, sandstone resting upon granite); and (*c*) angular discordance of beds with or without difference in lithologic character.[3]

[1] R. D. Irving, *U. S. Geol. Surv., Ann. Rep.*, VII, 1886, pp. 392, 393.

[2] Jos. Le Conte, *Elements of Geology*, 3d ed., 1893, p. 180.

[3] The phrase "eruptive unconformity," recently used to describe broad intrusive contacts of granite with older schists, is here excluded, on the ground that even if such structures are unconformities in any sense, they differ from erosional unconformities so fundamentally that the two cannot well be discussed together.

The criteria for identifying unconformites under varying conditions have been so carefully studied and systematized in recent years that they are generally well understood. The average student of geology knows that unconformities may be identified by means of basal conglomerates, by weathered zones on the underlying formations, by the truncation of dikes, faults, and other structures, by the general field-relations of the outcrops, by actually observed discordances and irregularities at contacts, and by still other means.[1]

At first the events signified by an unconformity were somewhat indefinitely realized. That the structure indicated an episode of erosion and the absence of strata which existed in other places, and that in some cases more or less disturbance had taken place in the intervening time, was clearly apprehended. Geologists are now generally agreed that an unconformity implies: (*a*) cessation of deposition (usually involving emergence, and often accompanied by deformation of the rocks); (*b*) denudation (usually by subaerial processes); (*c*) resumption of deposition (usually attending submergence, but often by terrestrial processes). It is also clearly understood that an unconformity represents a "lost interval," or lapse of time which is otherwise unrecorded at that place. The interpretation of this lost interval is the chief subject of the present paper, and is the one which most requires analysis and a definition of factors.

Writers of papers on stratigraphy not uncommonly state that a given unconformity is a great unconformity, or that another is a slight one; that it represents a vast lapse of time, or a minor episode only. The reader, however, cannot always know just what is meant by these expressions. From the context of such papers one may infer that the unconformity is considered great by one writer because of one feature, and by another because of a very different feature. A few examples will make this clear.

Regarding the unconformity at the base of the Keweenawan series, Van Hise says, ". . . . in areas in which the unconformity . . . . *is not great*, there is such a likeness in strike and dip of the two series as to suggest, at first, that the two are conformable."[2] Here apparently

[1] The criteria are exhaustively treated by Van Hise in a paper on the "Principles of Pre-Cambrian Geology," *U. S. Geol. Surv.*, *16th Annual Report*, Pt. I, 1896.

[2] "A Historical Sketch of the Lake Superior Region to Cambrian Time," *Jour. of Geol.*, I (1893), 127.

greatness is measured by the degree of discordance; the great unconformity being the one in which the lower series has been much more deformed than the upper, while the slight unconformity separates beds which have similar structure.

Walcott describes the break separating the Cambrian from the Belt series in Montana as a "slight unconformity"[1] because the dividing line is rendered very inconspicuous by the parallelism of the strata above and below. But on another page he refers to the same interruption as a "great stratigraphic unconformity,"[2] because it represents the loss of 3,000–4,000 feet of Algonkian strata by erosion. Here is an implication that an unconformity may be considered great if there is a large "lost interval," even if it is inconspicuous because the lower and upper beds are not discordant.

Referring to the unconformity between the horizontal beds of Ordovician and Carboniferous (Pennsylvanian) strata in eastern China, the present writer says:

> The absence of Silurian, Devonian and Lower Carboniferous series from Shantung indicates that the interval of erosion *may have* included all of those periods, and thus be worthy of rank as an unconformity of the first magnitude. It is possible, however, that sedimentation continued long after Ordovician time, and that the resulting rocks were subsequently removed by erosion, in all localities thus far examined. . . . .[3]

In this case lapse of time is made the sole criterion of greatness, and is discriminated from stratigraphic break or thickness of strata missing.

To summarize these different usages, then, an unconformity is sometimes called great (*a*) because there is prominent discordance of structure, (*b*) because a great thickness of strata is lacking, or (*c*) because the making of the unconformity involved a long lapse of time. It is true that these factors may all apply to any one unconformity, but they do not necessarily agree with each other. Great stratigraphic break is usually regarded as implying great lapse of time, and hence the two ideas are often combined in discussions and the expressions are used as if they were equivalent. In the study

[1] C. D. Walcott, "Pre-Cambrian Fossiliferous Formations," *Bull. G. S. A.*, X, 211.

[2] *Loc. cit.*, 204.

[3] Bailey Willis, Eliot Blackwelder, and R. H. Sargent, *Research in China*, I, Pt. I (1907), pp. 48–49.

of ancient pre-Cambrian terranes, or others which are devoid of fossils, it may not be practicable to determine how great a thickness of the record is lost, and, much less, the time through which the land conditions endured. The term "great," then, has value as indicating the geologist's opinion that the discordance is pronounced and that it doubtless implies great loss of record. In this sense it is a convenient word and has been of much service. Nevertheless, for the sake of clearness, the three factors should be carefully discriminated wherever that is feasible, even if their value cannot be definitely appraised.

To show that the stratigraphic hiatus[1] is not necessarily a measure of the lapse of time during which the unconformity was being made, I may cite Le Conte, who says: "Every case of unconformity represents a gap in the geologic record at that place. . . . . The loss of record may be partly by erosion, but mostly because not written at that place."[2] Unquestionably the stratigraphic break represents a lapse of time not now recorded in that place. But the region may have continued to be the scene of deposition during a part of that time, and the strata thus formed, and carrying the record, have been removed in the ensuing period of erosion.

By way of illustration we may take two unconformities which are somewhat similar as regards the length of the unrecorded interval, but are very different in time-value. At Rome, Georgia, Tertiary strata rest upon folded Cambrian rocks. In the Bear Lodge Mountains, northwest of the Black Hills of North Dakota, Tertiary beds may also be found upon Cambrian strata at certain points. The lost interval in each section is represented by all the strata from late Cambrian to Tertiary. In the first case, however, the deposition of sediments continued with brief interruptions from Cambrian to at least Pennsylvanian times, and then apparently was supplanted by erosion from Permian to late Tertiary times. In the second case sedimentation persisted until the end of the Cretaceous period, and gave way to erosion only during the Eocene period. It is plain, therefore, that although the stratigraphic break is nearly identical in

[1] By this term is meant the gap in the strata; i. e., where Devonian lies on Cambrian, the *stratigraphic hiatus* is equivalent to the Ordovician and Silurian systems.

[2] Jos. Le Conte, *Elements of Geology*, 3d ed. (1893), p. 181.

the two sections, the time-value is very different, being equivalent to five to seven periods of geologic history in the Georgian region, but to only one period, or a fraction of a period, in Wyoming.

The same thing may be brought out by examining one of these two unconformities at different points. Fig. 1 represents diagrammatically the pre-Oligocene unconformity of the Black Hills region. In a section taken at (*A*) horizontal Oligocene silts (solid black) rest on folded Algonkian slates and granite; at (*B*) upon tilted Permian shales, and at (*C*) upon horizontal late Cretaceous sandstone and shale. Judged from the standpoint of structural discordance, the unconformity is very great at (*A*), moderate at (*B*), and nil at (*C*). Regarded from the basis of stratigraphic hiatus, it is greatest at (*A*), less at (*B*), and least, although still noteworthy, at (*C*). But the time-value is probably much the same at all three points. The

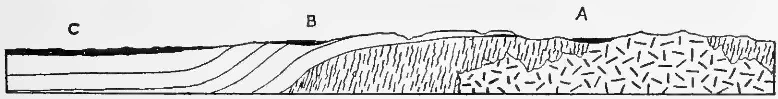

Fig. 1.—Pre-Oligocene unconformity in the Black Hills. The section is diagrammatic and generalized.

history of the region appears to be roughly this: Sedimentation was continuous from the Cambrian to the close of the Cretaceous period save for temporary episodes of erosion in mid-Paleozoic, and Jurassic times. No deformation attended these early changes, and the final result of the deposition was a thick blanket of strata lying horizontally across the region of the Great Plains. At the close of the Cretaceous period a low dome was bulged up, and during the Eocene the top of this was beveled off so that the pre-Cambrian rocks were exposed within encircling rims of younger beds. To this epoch of erosion the entire unconformity under discussion is due; and it would seem therefore that the time-value of the break is to be measured in this way rather than by the time-equivalent of the strata which are missing in any one section.

It appears, then, that unconformities seen in isolated sections may be prominent or obscure structurally, that they may represent a large or a small gap in the sedimentary column, and that they may

indicate a period of erosion of long or short duration, not to be estimated by the "lost record."

At this point it will be advisable to consider how these three factors may be determined with reference to a given unconformity. The degree of discordance may often be observed directly in sections, or may be inferred from observations of strike and dip. The stratigraphic hiatus may be discovered by correlating the beds above and below with a standard section of reference (supposing that such a section has been established), and thus determining what formations are lacking. These are matters of common knowledge and need not be dwelt upon here. The time-value, however, is not so easily ascertained, since observations on one section, or even on several adjacent sections, are not sufficient to bring out the facts. Let us start with the generally understood principle, ably presented in recent years by Chamberlin and Salisbury,[1] that *all unconformities are presumably limited in extent;* when traced in any direction they are eventually lost in a conformable sequence of strata. Thus the present eroded surface of North America—a future unconformity—merges into the continuous sediments of the seas about its borders. But some parts of this land mass have been out of water much longer than others, and so the unconformity which is to be will have a different time-value in different places. For example, if the sea-level should rise steadily the sea would encroach upon the land. With it would come the sedimentation for which it furnishes the conditions. In the southern Great Plains these modern sediments would lie first upon the Quaternary beds of the Gulf border. As the sea has been only recently excluded from this strip, the time-value of the intervening unconformity would be small—probably a fraction of the Quaternary period. Further slow advance of the sea would allow somewhat later deposits to be laid over a surface which seems to have been land since Miocene times. Continued encroachment would eventually allow deposits of still later age to be spread upon land which has been eroded presumably since the Eocene epoch. Here evidently the time-value is greater than in either the first or the second locality. The events and time-intervals are expressed graphically in the accompanying diagram (Fig. 2). This particular unconformity, it will be observed, began

[1] T. C. Chamberlin and R. D. Salisbury, *Geology* (1906), II, 222–24.

to be developed at *C* in Eocene times and ceased to be made at *C* in the fifth post-present epoch. Its time-value reaches its maximum at that place, covering ten to eleven epochs, while at the present Gulf coast (*A*) its value decreases to zero. This illustrates in a very simple way the principle that most unconformities gradually increase or decrease in time-value from place to place; that there is a waxing and a waning phase corresponding to recession and incursion of the sea or to the shifting of the sites of continental deposition. If the recession or invasion is very rapid, the lower or upper line of our diagram will approach the horizontal, but such changes will be matters of degree, not of kind.

Actually, however, the relations are rarely as simple as this, nor

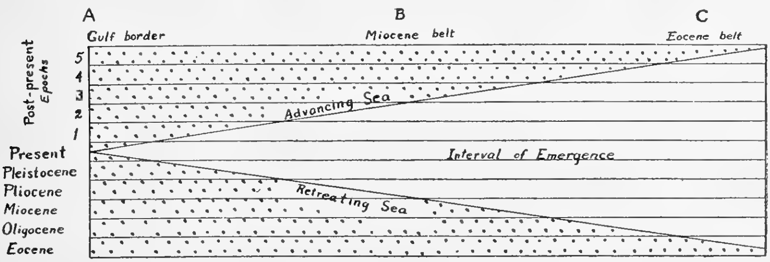

Fig. 2.—Diagram of a simple unconformity. The dotted area represents sedimentation, the blank space erosion. The horizontal lines denote equal time.

are the advances and retreats as regular. In the case just given it will also be observed that the stratigraphic hiatus varies almost directly with the time-value, a phenomenon which is somewhat common among unconformities, but is by no means the rule.

A case of average complexity may be formulated by imagining the middle Atlantic seaboard of the United States to be gradually submerged (Fig. 3). In an early stage of the encroachment of the sea modern sediments would be laid down upon Pleistocene sand and clay in the Chesapeake region (*A*); farther west younger beds would rest upon Miocene (*B*)—much as in the Texas example. Still later beds, however, would overspread the Piedmont belt with its ancient crystalline rocks. The discordance would suddenly change from slight to very great (*C*); and likewise the hiatus, which was equivalent to Tertiary-Modern on the coastal plain, would quickly expand to

a gap embracing perhaps Algonkian-Modern. Assuming as correct the current view that the Piedmont at this point was submerged in the Ordovician[1] period, but not later, we find that the time-value has also changed from Miocene-Modern to Ordovician-Modern, a great and relatively abrupt change, but not so great as that observed in the hiatus. Farther westward (*D*) submergence would cause modern sediments to be laid upon the truncated edges of the Paleozoic strata in the Appalachian Valley and Mountains. The discordance here is less, although still great, and the stratigraphic hiatus has decreased to perhaps Ordovician-Modern. The region is believed to have been eroded ever since the Permian period, and so the time-value is Permian-Modern. Now supposing the submergence to lap over upon the Allegheny plateau (*E*), angular discordance is quickly

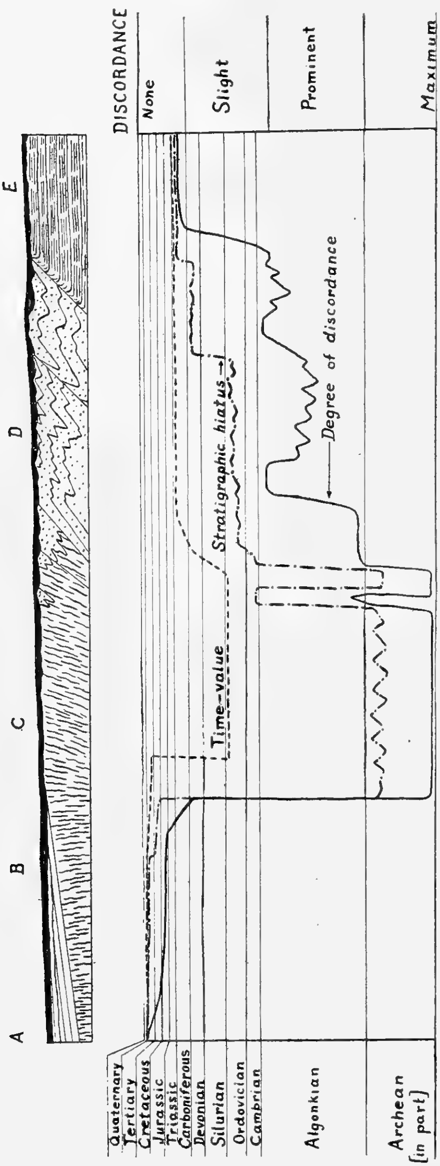

Fig. 3.—Hypothetical modern unconformity on the middle Atlantic slope. Positions on the diagram of curves coincide with similar positions on the generalized section.

[1] N. H. Darton, *Am. Jour. Sci.*, 3d series, Vol. XLIV (1892), pp. 50–52.

reduced to insignificance (although the eroded surface itself would be very uneven). Stratigraphic hiatus decreases to a value of Pennsylvanian-Modern. Time-value, however, suffers no corresponding change from the previous locality.

It appears then that the three factors, discordance, hiatus, and time-value, may vary suddenly and largely, but that they do not necessarily vary in the same degree, or even in the same phase. Time-value may decrease while hiatus increases. Discordance may occasionally become more pronounced as the lost record becomes smaller.

These considerations lead to the conception that unconformities are constantly fluctuating features of the stratigraphic record. It is also plain that the time-value of an unconformity can be determined only through the study of the geologic history of a considerable region, while discordance and hiatus can often be ascertained from individual sections.

The hypothetical case just considered, of an unconformity in eastern United States, fails, however, to give a complete picture of that unconformity since the assumed case represents only one withdrawal and advance of the sea. As a matter of fact we are to think of such a region as the Piedmont belt, or, let us say for the present example, the Canadian shield of ancient rocks, as being a land nucleus of varying dimensions, now expanding by withdrawal of the epicontinental sea, until it includes a continent, and then contracting to a mere island, perhaps smaller than Greenland, as the sea overspreads its shelving surface. These advances and retreats have taken place, not once, but many times, and the result is quite as many unconformities, *all of which blend landwards into one far greater unconformity* which records the continuous land condition of the central nucleus.

This is illustrated by Fig. 4, which shows an interpretation[1] of the submergences and emergences of a part of central United States since pre-Cambrian times, with the corresponding sedimentary series and unconformities. Vertical spaces represent periods of time, while on the horizontal line are scaled off certain broad provinces stretch-

[1] In this and other examples used in the present discussion the facts are but imperfectly known, nor does the writer profess to have made an exhaustive study of even those which are available. His interpretation of the history is not in any way essential, but will serve the purpose of illustrating the general principles.

ing from Labrador on the northeast (to the right) to southern Texas on the southwest (to the left). On the right, one sees that Labrador has been eroded from some time before the Cambrian down to the glacial period; and even then the deposition was accomplished by glaciers—a terrestrial agency. The unconformity there represents

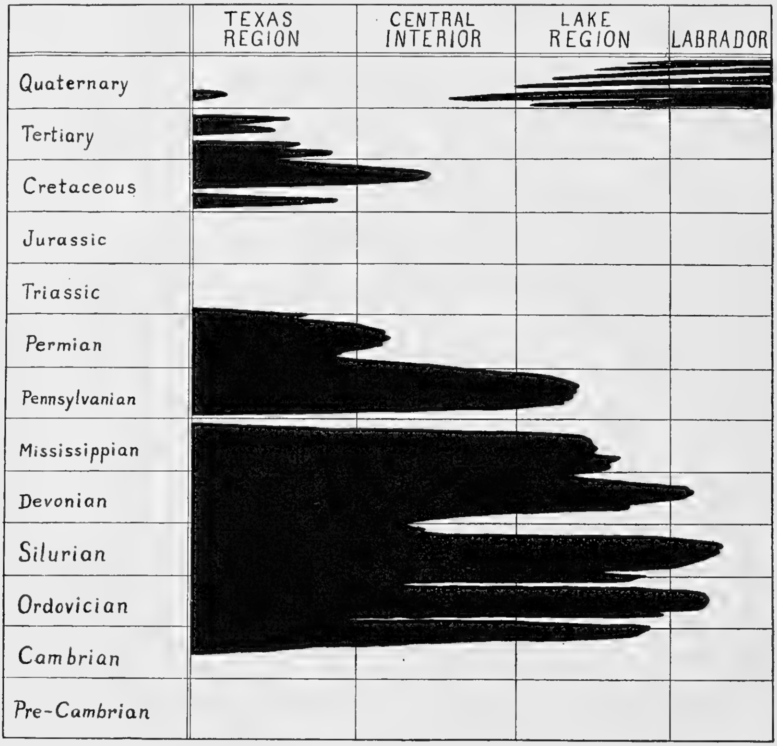

Fig. 4.—Diagram of an unconformity with lateral extensions and restrictions. The extent and duration of the principal periods and areas of sedimentation, with their corresponding rock systems, are shown in solid black. The white, on the other hand, denotes the time and extent of erosional conditions and corresponding unconformities.

a vast and presumably uninterrupted lapse of time. When traced southwestward, however, this great denudation-interval branches into many minor intervals which are intercalated between periods of sedimentation—the times during which the so-called sedimentary record was produced. The minor unconformities dovetail in with the sedimentary series, especially around the borders of the continent.

Traced toward the old land nucleus, the many little unconformities merge into a few, and finally into one all-inclusive unconformity. Traced seaward, the sedimentary wedges of the record expand into continuous piles of marine strata; for over much of the oceanic abysses sedimentation has probably been uninterrupted since the Archean period or before.

Our more familiar unconformities are to be thought of, then, as temporary expansions or wedge-shaped extensions of greater unconformities, and we must not be surprised if, when traced in one direction, they dwindle to nothing,[1] or if in another direction they expand so as to swallow up the entire sedimentary record.

SUMMARY

In the preceding discussion, the writer seeks to show that the words "great" and "slight" as applied to unconformities are often ambiguous and in need of definition; that, where these things can be determined, it is important to know whether the *structural discordance*, or the *stratigraphic hiatus*, or the *duration of erosion*, is the thing that is great or small.

It appears that the stratigraphic hiatus or lost record is not necessarily a measure of the time which elapsed while the unconformity was being produced. The two may be nearly equal, but on the other hand the lost time may be much less than the lost record. It cannot well be greater.

Also, all three factors change from place to place—the discordance and hiatus often suddenly and capriciously, the time-value usually more gradually.

Many, if not most, unconformities are merely lateral extensions of much more persistent unconformities. The main unconformity denotes a very long duration of terrestrial erosive conditions, while the projecting wedges record the backward and forward migrations of belts of sedimentation around the borders of that land.

The entire geologic record then is not to be conceived of as a pile of strata, but as a dovetailed column of wedges, the unconformities and rock systems being combined in varying proportions. The former predominate in some places and periods, while the latter prevail in others.

[1] This conception is admirably explained by Chamberlin and Salisbury in *Geology*, II, chaps. iv, v.

Reviews

Early Devonic History of New York and Eastern North America. By JOHN M. CLARKE. New York State Museum, Memoir 9, 1908.

Our knowledge of the Paleozoic faunal history of North America is derived largely from the faunas of the interior epicontinental seas which were spread out upon the continent from time to time, sometimes as great tongue-like embayments, and again as great sheet-like expansions which covered large areas of the continental surface. These shallow epicontinental seas teemed with life and the sediments deposited in them are frequently abundantly fossiliferous. The various elements in these faunas usually give evidence of being immigrants, and the originating tracts in which they were evolved are believed usually to have been in shallow areas on the borders of the oceanic basins. In these border regions having more direct communication with the permanent oceanic basins, the physical conditions were doubtless more nearly continuous than in the more or less transient interior epicontinental seas, and the life history also was probably less liable to abrupt changes. At the present time the Paleozoic rocks of most of the border region of the continent are deeply buried beneath the sea or beneath younger strata, the most notable exception to this condition being found in the great eastern angle of the continent which includes the maritime provinces of Canada. Because of their peculiar relations to the faunas of the interior, any contribution to our knowledge of the ancient faunas of these maritime provinces is received with especial favor. A most notable contribution to the paleontology of this region is a memoir on the *Early Devonic History of New York and Eastern North America*, by the Director of Science of the New York Education Department, which is devoted to a discussion of the lower and middle Devonian faunas of the Gaspè region.

Before entering upon a description of the faunas to be considered, Dr. Clarke has sketched the geology of the region which was first worked out by Sir William E. Logan many years ago. A glowing tribute is rendered this great pioneer in the investigation of Canadian geology, who "sought and found the key to the geologic structure of the country; and so conclusively and with such admirable finish was the work of this master hand accomplished that in all the years since elapsed, from 1844 and 1845, little has been added to, and naught subtracted from his achievements."

The Gaspè peninsula is the northeastern extremity of the Appalachian mountain system, and the geologic structure consists of a series of parallel folds similar to those so well known farther to the southwest, and formed by the same great earth disturbances. The Devonian rocks with whose faunas the memoir is concerned lie unconformably upon older Paleozoic formations. They include the Gaspè limestones and sandstones of Logan. The Gaspè limestone attains a thickness of 2,010 feet and is frequently highly fossiliferous. Three divisions are recognized, the St. Alban limestone below, followed by the Bon Ami limestone, and this again followed by the Grand Grève limestone. The Gaspè sandstones, according to Logan's estimates, attain the enormous thickness of 7,000 feet, but this estimate may be too large by reason of the repetition of some beds by faulting.

From the St. Alban beds a fauna of 51 species is described "of which fully one-half occur in the typical Helderbergian faunas (Coeymans and New Scotland) to the southwest." The fauna of the Bon Ami limestone is small and of much less importance, but the Grand Grève limestone has furnished a fauna of about 150 recorded species. This fauna

has a less proportion of community of species with the Helderbergian but still a substantial number of species (21 identities and 14 close affines). With the Oriskany there is a larger community of species (39 identities and 13 affines) and so commanding is this percentage and the composition of the congeries itself, consisting as it does of the most typical species of the Oriskany, that it compels this inference: The development of the Oriskany fauna was synchronous with the prevalence of the Helderbergian fauna in this region and the differentiation of the two faunal elements, which we commonly recognize in the Appalachian regions as Helderberg and Oriskany, was subsequent in date to the development of the combined faunas together in Gaspè. Thus again we have evidence that the Gaspè basin was a center of dispersion of these two faunas and that the direction of this dispersion so far as the facts now indicate was still toward the southwest.

The marine fauna of the enormously thick Gaspè sandstone is of but limited extent, and occurs in a comparatively thin horizon of calcareous sandstones which probably lies near the base of the entire series. This great accumulation of arenaceous sediment seems to have been deposited in a great costal lagoon into which terrigenous sediments were rapidly swept. The stratum of marine sediments probably represents overwash of the outside waters in time of stress, bringing in the marine organisms which are now found as fossils. Only about fifty species are recorded in this fauna of which "one-seventh to one-sixth are survivors of the Oriskany element in the Grand Grève limestones. With the Hamilton faunas from

the calcareous shales of the Skaneateles, Moscow, and Ludlowville formations of New York, this Gaspè sandstone fauna presents a predominant agreement, having sixteen identities and six affines, or approximately 50 per cent. of the fauna." The presence of this Hamilton element in the fauna is indicative, according to Dr. Clarke, of an invasion of the latter fauna from the west, while the earlier Helderberg-Oriskany fauna still occupied the sea in the Gaspè region. An alternative interpretation, the invasion of the Hamilton fauna from the south along the Atlantic border, should perhaps be considered. The Onondaga fauna is not differentiated in the Gaspè region, it being one of the undifferentiated elements in the Grand Grève fauna.

The evidence is thus fairly cumulative that the Gaspè basin was an area of rapid evolution during the early Devonic and a center of dispersion from which the lines of immigration departed westward. We cannot now say that they did not also lead thence eastward. In a later Devonic stage this basin was the recipient of migrants from the west. The course of migration into and out of the interior Appalachian waters was along a seaway which cannot yet be traced step by step, but evidently parallel to the Appalachian folds. There seems now a fair presumption of a continuous connection between the Gaspè basin and the east by way of the Connecticut trough into eastern New York. The tangible evidence of this connection will be set forth more fully hereafter. The Gaspè Eodevonic basin extended from the Canadian Archean shield at the north to the limit of the Dalhousie beds on the south and contracted in the middle Devonic. Apparently there was no free and open connection between it and the parallel contemporaneous embayments at the south in which the Chapman and Moose River sandstones of Maine were set down.

The faunas described in this Memoir are illustrated by 48 finely executed lithographed plates which are fully up to the standard so long established and maintained by the State of New York in her paleontologic publications. Not the least attractive feature of the book is the frontispiece, a reproduction in color of the painting by Frederick James of that most striking landmark of the Gaspè coast, Percé Rock.

S. W.

Textbook of Petrology. By F. H. Hatch. New York: Macmillan.

This book, which is a fifth edition, revised and rewritten, contains a summary of the modern theories of petrogenesis, a description of the rock-forming minerals, and a synopsis of the chief types of igneous rocks and their distribution as illustrated by the British Isles. The work is concise and somewhat comprehensive and may serve very well for an introduction to the study of igneous rocks, with the aid of the microscope. Part I treats

of the physical characters of igneous rocks, their mode of occurrence, structure, texture, and composition. In Part II some seventy pages are devoted to mineral descriptions, and in the back of the book are four pages of tables to be used for the determination of the common rock minerals. The usefulness of this part of the work would be greatly increased if it contained a colored plate showing the maximum birefringences of minerals for various thicknesses of plates. It is presumed that the student has a knowledge of optics. Part III is devoted to the classification of igneous rocks, the method being essentially the qualitative system now in use. Part IV devotes about one hundred pages to the distribution of igneous rocks of Great Britain. This part of the work is illustrated by many text figures and is a brief summary of the petrography of the British Isles. The work is well arranged and includes much useful data. The American student of igneous rocks could wish for a rather more comprehensive treatment of differentiation, magmatic stopping, and related subjects; with a brief résumé of the quantitative system of rock classification, the use of which is increasing on this continent.

W. H. E.

The Ephemeral Volcanic Island in the Iwôjima Group. By T. Wakimizu. Publication of the Earthquake Investigation Committee in Foreign Languages, No. 22, Section C, Art. 1. With Plates I–XII. Tôkyô, 1908.

The island appeared February 1, 1905, three nautical miles east of M. Iwôjima. It was three miles in circumference, 480 feet in height and contained about 200 acres in area. The lava was of the olivine-augite-andesite type resembling closely that of Mt. Pipe in Iwôjima. From its geographic position and nature of ejecta it seemed clear that the ephemeral island was a volcano belonging to the same volcanic line as the three principal volcanic islands of the Iwôjina group. On June 16, 1905, the island had almost disappeared. The cause of submergence was attributed to the erosive action of the waves and possibly to depression of the crater rim.

C. J. H.

Formation of Geodes with Remarks on the Silicification of Fossils. By Ray S. Bassler. From the Proceedings of the United States National Museum, Vol. XXXV, pp. 133–54, with Plates XVIII–XXIV. Washington, 1908.

The author finds in his study of the formation of geodes in the Keokuk geode beds and in the shales and limestones of the Knobstone division of the

Mississippian that their origin is often traceable to a beginning in fossils. The geodes are invariably found in or near joint planes and rifts along which waters have had easy passage. A large majority of the geodes in the Knobstone may be traced to an origin in a fractured crinoidal stem or brachiopod shell. In all the specimens described deposition of silica in the fractures has been preceded by a complete silicification of the fossil itself. The crystallizing force of the addition of silica in the fracture continues to rupture the fossil more and more which later forms a typical geode.

The author maintains that the replacement of the original calcareous material of fossils by silica in siliceous pseudomorphs does not take place at the time of deposition of sediment, but rather that silicification proceeds as weathering advances. It has been observed that limestones yielding siliceous pseudomorphs contain in the unweathered portions calcareous fossils. The embedded part of the fossil is often calcareous while the exposed part is siliceous. From these lines of evidence he concludes that silicification of many fossils is a present process. C. J. H.

Mineral Resources of the Philippine Islands. By WARREN D. SMITH, Chief of the Division of Geology and Mines. 39 pp., 6 pls., map. Manila, 1908.

This bulletin marks the beginning of an annual statement of the mineral production of the islands. The plan adopted is similar to that of the U. S. G. S.

The nonmetallic products are first considered. A low-grade, sub-bituminous coal, suitable as a gas-producer, is mined. It is abundant, but coal-mining is difficult owing to complex folding and faulting. Some of the mines are promising. A good quality of lime is manufactured at Binangouan. Raw materials for the manufacture of cement are abundant. The limestone is very free from magnesia. Mention is made of natural gas, petroleum, building and monumental stone, abrasives, gypsum, phosphates, sulphur, salt, magnesite, mineral waters, Fuller's earth, mica, manganese, and precious stones. The brick, tile, porcelain, and pearl industries are of little importance.

Gold is the only metal now mined to any notable extent. A profitable mine is worked in Benguet. Deposits of copper, silver, lead, iron, and tellurium occur, but are not actively mined.

Production in 1907: gold, 4,540 oz., silver, 83 oz., iron, 436 tons, coal, 4,545 tons. C. J. H.

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Beauty

Doctors regard beauty from the point of view of health, and tell you that a good natural complexion and a fair, soft skin are necessary essentials of beauty. They never disagree about that, nor do they disagree about the merits of

Pears' Soap

From the Doctor's Point of View

which is the most perfect beautifying agent known, being pure in every particle and possessing those special and unique qualities which render the skin pure, clear and of exquisite softness. The beauties of six generations have acknowledged PEARS' to be

The Best Aid to Beauty

OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

JOURNAL OF GEOLOGY

MAY–JUNE, 1909

UPPER CARBONIFEROUS

GEORGE H. GIRTY[1]

VI

The Upper Carboniferous, rather in contrast with the Lower, was a period of emergence of shores and of shallowed waters, and it presents the variety that appertains to such conditions. In considering the stratigraphic relations of the Pennsylvanian and Permian one cannot fail to be struck by the local character of the phenomena, and the vast amount of detail, from which it is difficult to disengage facts of broader significance. One of the facts of larger moment is the general unconformity which occurs at the base of the Pennsylvanian rocks. The extent of the phenomenon may be gauged by this: that an unconformity probably occurs at this horizon all the way from Pennsylvania to the Mexican boundary, except possibly in the deeper troughs. The underlying strata range in age from pre-Cambrian to Upper Mississippian. This is evidently, therefore, an unconformity by overlap, but the overlap is sometimes not appreciable unless extensive areas be kept in view. Very rarely, I believe, is any angular unconformity to be observed, but there are basal conglomerates and in many places unmistakable evidence of erosion in the subjacent strata. Some of the most noteworthy instances of erosion are to be found in Missouri where shales of Pennsylvania age were deposited in sink holes and subterranean channels in the

[1] Read before Section E of the American Association for the Advancement of Science, at the Baltimore Meeting, December, 1908.

Lower Mississippian limestones. On the other hand, evidences of erosion are often wanting and sometimes any physical suggestion of an interruption in sedimentation. A striking instance of this sort occurs in southern Arizona. In the Bisbee area limestones of Pennsylvanian age rest upon limestones of Lower Mississippian age, the two series being extremely similar in physical characters, though carrying different faunas. The same condition probably exists in the Redwall limestone of the Grand Canyon region, whose lower part is of lower Mississippian age and whose upper has furnished, according to Meek, a long list of Pennsylvanian species. The presence of this unconformity is to be detected therefore not always by local evidences of erosion or changes in sedimentation, but sometimes only by paleontologic evidence in the abrupt and great change in the faunas and floras, and by stratigraphic evidence in the overlap, sometimes appreciable only by considering rather wide areas.

Inasmuch as we find this extensive area in which a hiatus exists at the base of the Pennsylvanian, and inasmuch as over part of the area unmistakable evidence of erosion is found, the inference is probably a safe one that everywhere within this region the hiatus is partially at least due to post-Mississippian erosion.

The presence of this erosion period implies the existence of a land surface over the eroded area, for the alternative hypothesis of submarine erosion may probably be disregarded.

The boundaries of the land cannot be exactly defined. On the east I would judge that it must have followed a presumably irregular line southwestward from northern Pennsylvania to southwestern Texas. At least, there is a well marked unconformity west of such a line, while in some sections east of it, sedimentation appears to have been continuous from the Mississippian into the Pennsylvanian. An estimate of where the boundary lay on the western side is conditioned somewhat by our correlations of the western Mississippian faunas with the eastern and with one another, especially as to areas over which the Upper Mississippian is wanting.

It is pretty well established by many observations that faunas with a Kaskaskian facies are not known west of the Mississippi Valley. There are, however, some faunas peculiar to the West which may be of Kaskaskian age. The best known and most notable of these

occurs in the Baird shale of California, and has not been found elsewhere on the continent. It is characterized among other things by the European *Productus giganteus*, and can be correlated more easily with the Mountain limestone of Europe than with our own Mississippian.

Although the *Productus giganteus* fauna strictly speaking is, so far as we know, restricted to California, there is another western fauna having a different facies which I am inclined to correlate with it. It comprises little besides corals, chiefly large Cyathophylloids. I have noted it in Utah, Montana, and Idaho. We have some reason to believe that it represents the Upper Mississippian to the East and the Baird fauna to the West. If this is so, the evidence upon which we chiefly relied for recognizing post-Mississippian erosion—the absence of the Upper Mississippian—is lacking over this area and the hypothetical land mass would appear to have extended westward on its northern margin no farther than western Montana and central Utah.

As to what were probably the northern and southern boundaries, evidence is wanting, Carboniferous strata being absent in Canada across its trend and absent or concealed by Cretaceous overlap in Mexico except just over the Texas border in the state of Chihuahua.

The unconformity of which I have just been speaking occurs at the base of the Upper Carboniferous. There is, however, a second important unconformity which occurs in the middle of the Upper Carboniferous and is less widespread as to the area in which it has been recognized. Like the other, it is marked rather by overlap than by discordance. The overlap is most conspicuous in western Texas and New Mexico, but equivalent strata, distinguished from the preceding ones by a distinct faunal change, and in some cases by basal conglomerates, probably extend into Arizona and Nevada, or even farther.

Lithologically the beds of the Upper Carboniferous and Permian present the greatest variety, and about the only truth of broad applicability has long been known. I mean that in eastern North America the sediments of the Upper Carboniferous are chiefly shales, sandstones and conglomerates with some thin limestones, while in the West the limestones have a much larger development, and

coals, which toward the East play so important a part, if not in thickness at least economically and significantly in the Carboniferous sediments, are there practically absent. From this it has been justly inferred that the character of the eastern Carboniferous indicates shore and estuarine conditions of deposition, while that of the western indicates marine conditions of deposition. There are, however, vast amounts of sandstone and shale in the Upper Carboniferous of the West.

It seems to be true that the greatest deposits of limestone in this series are found rather to the Southwest than to the West and the most notable thicknesses of sandstone and conglomerate rather to the Northeast than to the East.

There is one other phenomenon of more than local interest which should not be omitted in a commentary on the lithologic features of the Upper Carboniferous. I refer to the red beds of the West and Southwest. The age, the stratigraphic relations, the sources, and the cause of the peculiar coloration of this great series of sandstones and conglomerates form a problem of no mean difficulty and importance. Although it is difficult to trace these beds stratigraphically, and though fossils are rarely found in them, we know now that sediments of this character were formed rather early in the Pennsylvania and successive manifestations recurred at various periods on into the post-Cretaceous. That there were continuous red beds conditions during all this period seems out of the question, and also that red beds conditions repeatedly recurred. Some of the occurrences can probably be best explained as a reworking of older materials under conditions unlike those which determined their original character.

In considering the faunas of the later Paleozoic—those of the Pennsylvanian and Permian—several facts of a general nature can be stated. The Upper Carboniferous faunas of western North America have a facies markedly different from those of the eastern part and are closely comparable to the corresponding faunas of Asia and eastern Europe. A second fact of general import seems to be that, quite in contrast to the unstable physical conditions in which they lived, these eastern faunas, which range, let us say, westward to the Rocky Mountains, are remarkably uniform both in their geographic distribution and in their range. I would be far from saying that the

Upper Carboniferous faunas of the continental basin do not show differentiation during this long interval, for the Pottsville group has a distinct fauna and appreciable changes occur in the later Pennsylvanian. But the changes are by no means so marked as one would be led to expect from the thickness of the strata involved, the extent of the territory they cover, and the varying conditions of the time and the place. The truth of this statement will be appreciated upon a consideration of the Mississippian series of the Upper Mississippi Valley and the subdivisions which have been established in it.

When we speak of the variety of conditions under which the sediments in question were laid down, and remember that they include the great coal deposits of this era, we are led to inquire whether the faunas are marine or fresh water, or perhaps both, with the important difference in facies which such difference in habitat would doubtless entail. Fresh-water faunas, or at least fresh-water genera and species, have been recognized elsewhere in the Carboniferous, notably in the Coal Measures of England and the Permian of Russia. In North America, although we have a facies which appears to be non-marine, there are no Carboniferous faunas which in my belief can be called fresh water. The facies in question recurs frequently, particularly in the Appalachian region, and manifests little change in its general aspect, although appearing at widely different horizons in the Pennsylvanian. It is very restricted in variety though often abounding in individuals. A mollusk probably identifiable as *Naiadites elongatus* Dawson is a characteristic feature. Ostracods are also abundant, and the large bivalve Crustaceans, *Estheria* and *Leaia*, sometimes occur. *Spirorbis* is another type frequently met with, while fish scales, fragments of *Limuloid* Crustaceans, and wings of insects are rare. Usually this peculiar assemblage of forms is associated with abundant coal plants.

The genus *Naiadites* was described by Dawson from the Nova Scotia Coal Measures, in which it occurs with a fauna similar to that sketched above. Dawson regarded the sediments and faunas as representing fresh-water conditions, and considered *Naiadites* to be related to the Naiads of our fresh-water lakes and rivers.

The fresh-water mollusks of the English Carboniferous were included by Dr. Wheelton Hind under the three genera, *Anthracoptera*,

Anthracomya, and *Anthrocosia* in a valuable monograph published a few years ago. Later, after studying specimens of *Naiadites* from Nova Scotia, he reached the conclusion that *Anthracoptera* and *Naiadites* were the same genus.

Thus far the balance of evidence and opinion seems to be in favor of the fresh-water habitat of the fauna. On the other hand, externally and internally, *Naiadites* is extremely like the marine genus *Myalina*, and Dr. Hind has referred many of our marine *Myalinas* to *Naiadites*. In fact, he has even placed the names of some of our American *Myalinas* which always occur associated with marine faunas in the synonymy of English species of *Naiadites* which are supposed to be strictly fresh water. Furthermore, the fauna under consideration is in some instances associated with specimens of *Lingula* and *Aviculipecten*. The living *Lingulas* sometimes inhabit brackish waters near the mouths of rivers, but never the fresh waters of lakes and streams, while the living *Pectinoids* are strictly marine. The fossil Pectinoids in question are small and depauperate examples and belong to a rather peculiar group, that of *Aviculipecten whitei*.

This assemblage can hardly be explained as due to the accidental commingling of types having different habitats. If it consisted of fresh-water animals washed out to sea we would expect to find the fresh-water types few and the marine ones numerous, varied, and characteristic. Such is not, however, the case. One would not a priori much expect to find marine animals washed into a fresh-water fauna, and in such an event we would probably look for an entire marine fauna, or, at least, granting that only a few specimens were washed in, that some such invaders would be of the usual marine types. Instead, the alien forms are always limited to one or two peculiar varieties. That abundant and differentiated marine life was always at hand waiting for an opportunity to migrate wherever the conditions became possible seems to be evidenced by the occurrence now and again of marine faunas in close association with beds of coal. On the whole, it seems most reasonable to regard this fauna as a natural assemblage of species selected and modified by a habitat, if not in strictly marine, at least not in strictly fresh waters.

There is another reputed occurrence of fresh-water forms in the Carboniferous, reported by Mr. Walcott from the Eureka district, of

Nevada. I have examined the fossils in question only casually, and it has been many years since I have seen them at all, but I doubt whether in this instance, any more than the other, the evidence warrants saying more than that they are possibly non-marine.

The Upper Carboniferous faunas of the West appear to be better differentiated than those east of the Rocky Mountains. At least three well-marked facies can be recognized. The oldest of these is found in the limestones whose occurrence has already been mentioned, resting directly upon Lower Mississippian limestones of similar character in Arizona and probably in Utah. This fauna is succeeded by one which is best considered from its development in the Transpecos region of Texas, because it is there more highly developed, more favorably studied, and more determinable in its stratigraphic relations with higher beds. It occurs in the Hueco formation which is 5,000 feet thick, and is practically calcareous throughout. As has already been noted, the Hueco formation by overlap rests upon the pre-Carboniferous in this region. The Mississippian faunas, together with the earlier Pennsylvanian ones, appear to be absent. The Hueconian fauna is widely distributed over the West, ranging indeed into Alaska, while it is even recognizable in Asia and eastern Europe. Most of the occurrences of Carboniferous in the West can be referred to this series, although some or them present more or less distinctive facies. The more important of the facies provisionally referred to the Hueconian are these: that of the Aubrey group of Arizona, rather widely distributed; that of the phosphate beds of the Preuss formation, local in Utah, Idaho, and Wyoming; the *Spiriferina pulchra* fauna with a considerable distribution in Idaho, Wyoming, Utah, and Arizona; the fauna of the McCloud limestone of California probably extending into Nevada; and that of the Nosoni formation of California (in part the "McCloud shale"), apparently recognizable to the eastward and to the North and West, even into Alaska.

In the Transpecos the beds of the Hueco formation are succeeded by those of the Guadalupe Mountains. The contact between the Hueco formation and the Guadalupian series is obscured by faulting and by desert deposits, but it is assumed that the interval between the highest known beds of the one and lowest known beds of the other is not a long one and that no unconformity exists between them. The

Guadalupian includes two formations, the Delaware Mountain formation and the Capitan limestone. The Delaware Mountain formation consists of sandstones and limestones, largely arenaceous to the North and largely calcareous to the South. The Capitan consists of whitish limestones and dolomites. Thus constituted the Guadalupian series is about 4,000 feet thick. The faunas of the two divisions of the Guadalupian are closely related to one another. They are very rich and varied, having already furnished over 325 species. The Guadalupian fauna is peculiar. But few of its species are common to the other American faunas and some of its genera, such as *Richthofenia*, *Leptodus*, *Geyerella* and *Aulosteges*, have not been noted elsewhere in the western hemisphere. Even the more common genera are in many cases represented by uncommon types. As an instance may be mentioned the genus *Composita* (*Seminula*), which, by the way, seems to be rather characteristic of our American faunas where it is ever present and ever abundant. In the Guadalupian this genus develops a bi-lobed species with a sinus on the dorsal as well as on the ventral valve and a deeply emarginated anterior border.

It is possible that the Guadalupian fauna may have an equivalent in California in the Robinson formation, in which I have noted a species of *Leptodus*, and a suggestion is contained in some forms from Nevada, but aside from this the Guadalupian facies is known only in a limited area in New Mexico and Texas.

It remains to speak of still another western fauna having a pronounced facies, a wide distribution, and a range through a considerable thickness of rocks. I mean the fauna of the so-called Permo-Carboniferous of the Wasatch Mountains, and the Permian of Mr. Walcott's Grand Canyon section. This fauna, which ranges also into Wyoming and Idaho, comprises little else than pelecypods, of which *Myalina* and *Aviculipecten* are the most common types, the Pectinoids being especially abundant and varied. It may tentatively be correlated with the Guadalupian (Delaware Mountain division), athough it presents but little resemblance to the Guadalupian fauna as at present known. At least, it appears to occupy a corresponding position in the section, resting upon strata which in the light of our present knowledge are correlated with the Hueco formation.

These western faunas are more easily correlated with those of

Europe, especially Russia, than with those much nearer geographically, in eastern North America. Indeed, the correspondence of our western faunas with those of Russia is truly remarkable. The Russian series consists, in ascending order, of the Mountain limestone, or *Productus giganteus* zone; the Moscovian, or "Lower Carboniferous;" the Gschelian or "Upper Carboniferous;" the Artinskian or "Permo-Carboniferous" and the Permian. One school of Russian geologists includes the Artinskian or Permo-Carboniferous beds in the Permian, and some Americans have followed them, but this seems to be of doubtful propriety. Murchison, DeVerneuil, and Keyserling mistook the Artinsk sandstone for the Millstone grit and distinctly excluded it from the Permian. If the faunal relations demand this extension of the term Permian to the Artinsk it would be justifiable, but such is not the case. At least, this appears to be the judgment of Tschernyschew, the chief of the Russian Survey, and other distinguished paleontologists at all events. In this recital the term Permian is used in exclusion of the Artinsk beds.

The *Productus giganteus* zone seems to be represented on this continent by the Baird shale of California whose fauna likewise contains *P. giganteus.*

The Moscovian, which has a facies very like our common Pennsylvanian faunas, may be compared with the earliest Pennsylvanian of Arizona and Utah, the term "Lower Carboniferous," as used by the Russians, having no relation to our own Lower Carboniferous or Mississippian. The Gschelian is clearly related to our Hueco formation, but with this zone the closeness of the analogy ceases. One is tempted to place in alignment the Artinsk and Permian which succeed the Gschelian in the Russian section, with the Delaware Mountain formation and Capitan limestone which succeed the Hueco formation in the American section, but such a correlation is neither sharply contradicted nor substantially supported by the faunal evidence. In fact, as exhibited in the literature, the faunas of the Artinsk and Permian are much less varied and individualized than those of the Guadalupian. The following suggestions are made with the diffidence of second-hand and imperfect knowledge, but it would appear that after the Gschelian stage there was in the Russian area a gradual progression from marine to at least near-shore conditions. This

seems to be indicated by the great reduction in the marine facies, especially in the brachiopod representation, so that in the Permian there remains scarcely a tithe of the greatly diversified brachiopod fauna of the Gschelian, and by the introduction of fresh-water types of which not less than 200 species have been recognized. Apparently the typical Permian deposits of Russia represent local and not normally marine conditions of deposition.

I am tentatively assuming, on the grounds noted above, that the Guadalupian is equivalent to the Permian or to the Permian and Artinskian, the one representing a normal marine and the other an abnormal facies. It may prove, however, that all or part of the Guadalupian is younger than the Permian. A recent monograph by Tschernyschew gives a complete account of the brachiopods of the Gschelian, but the other types remain undescribed or else the descriptions are badly scattered. The literature on the Artinskian and Permian is also somewhat scattered, but one receives the impression that the brachiopods of the latter do not present many positive differences from those of the Gschelian though much less varied, and reduced to a few types of long range and wide distribution. Whether the same is true of the rest of the fauna it is difficult to say, although it seems rather doubtful. In view of the striking difference between the faunas of the Guadalupian and the Hueco formation, in which the brachiopods are most in point, of a lack of a corresponding difference between the Gschelian and Permian, of the marked resemblance of the brachiopods of the Hueco and Gschelian, and of the lack of agreement between the Permian and Guadalupian, there is a possibility, if not a certain probability, that the Artinsk and Permian may be correlated with the Hueco formation.

Having compared the western faunas with those of Russia, let us consider what their relations may be with those of eastern North America.

We find in such a comparison really fewer resemblances than with the faunas of Russia. Of the three or four western faunas which I have noted, by far the greatest resemblance is to be found in the oldest of all; perhaps because it is least varied and most generalized. The Hueconian presents much more numerous and extensive differences and the Guadalupian the strongest of all. In fact, of the 325 species recognized in the latter scarcely a single variety can be definitely

identified in the eastern faunas. The species are in most cases not only not the same but they are not even similar. It seems possible to me that the Hueconian fauna may be equivalent, in spite of its differences, to the faunas of the East, but hardly that of the Guadalupian. This opinion is based upon the striking differences existing between the Guadalupian and any eastern fauna, upon the much closer resemblance of the eastern faunas with the Hueconian fauna, and upon the important differences between the latter and the Guadalupian. However, as so little is known of the character and potency of the environmental conditions under which these faunas existed, there is a possibility which I do not wish to deny that the relations noted may have to be ascribed to the environment element, rather than to the time element.

Provisionally I am regarding the Guadalupian as younger than any known faunas of the eastern region, thus interpreting the faunal differences of the Hueconian when compared with the Pennsylvanian and Permian of the East, as due to environment rather than to time. There is some evidence, however, that the Hueco formation should be considered younger than the so-called Permian of the Kansas section instead of equivalent to it. Mr. Beede has recently described several occurrences of a fauna which I should perhaps have mentioned as representing one of the interesting and important differentiations found among the faunas of the Upper Carboniferous of the East. They were obtained from the red beds of Oklahoma and the horizon is known to be considerably above the highest occurrences of invertebrate fossils in Kansas. This fauna appears to me to present more important differences from the Kansas Permian than exist between the latter and the underlying beds referred to the Pennsylvanian. Accordingly, if any of the faunas of the eastern section are to be classed as Permian it would appear to me more appropriate that the dividing line should pass above rather than below the Kansas Permian. When compared with the western faunas, that described by Mr. Beede is far from being identical either with the Guadalupian or with any facies of the Hueconian, but of the two its affinities appear to be decidedly with the latter. If this evidence is to be relied on, even Mr. Beede's fauna is older than the Guadalupian and if the latter is equivalent to the Permian, older than the Permian.

Another fact which might be brought forward to support the contention that even the Hueconian is younger than the Kansas Permian is the important unconformity which preceded Hueco sedimentation and was accompanied by a corresponding change in the subsequent fauna. According to this interpretation, the oldest of the western faunas, which, as already noted, presents a closer resemblance to the characteristic Pennsylvanian fauna than any other, would correlate with all of the eastern section to the top of the Kansas Permian. Its failure in the strata which it occupies to measure up to the thickness of the Mississippi Valley section, and the absence from it of some of the modifications found there, would be ascribed to pre-Hueconian erosion. After this episode there was, it might be claimed, a faunal change represented in the Hueconian fauna of the West and in Mr. Beede's red beds fauna of Oklahoma, this in turn being succeeded by the Guadalupian fauna.

Though keeping this interpretation of the facts well in mind, I am at present adopting the more conservative hypothesis—that the top of the Kansas Permian may be as high as the base of the Guadalupian; but that no part of the latter correlates with any part of the invertebrate-bearing beds of Kansas.[1] From this it would follow that if the Guadalupian is equivalent to the Russian Permian then the Kansas Permian is distinctly older, possibly Artinskian, possibly Gschelian. If, on the other hand, the Kansas Permian is really equivalent to that of Russia, the Guadalupian would appear to be a distinct and faunally well characterized series younger than the Permian.

It is well in considering the use of the word Permian for North American strata to discriminate Permian time, Permian conditions, and Permian faunas. Permian conditions, or conditions such as were prevalent in Russia during Permian time, might recur more than once. Indeed, it is safe to say that most conditions are repeated in one area or another many times during geologic history. Permian conditions would give character to the sediments and to the faunas of Permian time. But, while the same peculiarities of sedimentation would presumably be manifested at every recurrence of Permian conditions, the character of the fauna would be partially determined by another factor, the biologic factor. It is conceivable, or even probable, that

[1] By this expression I mean to include the Marion and subjacent formations.

similar conditions acting upon two unlike faunas might produce rather similar results. The resulting faunas might be less diverse than the original ones. This is perhaps particularly true of conditions such as appear to have prevailed in the typical Permian, conditions hostile to marine life, hostile especially to the continuance of specialized types of life, at least of brachiopods.

In the Kansas section we appear to have a single faunal sequence gradually passing to extinction but undergoing some minor modifications in the process. The upper portion of the sequence is the Kansas Permian. We are told by those who are familiar with both, that Permian conditions are manifested in the so-called Permian sediments of the Mississippi Valley. I believe that there is no strictly Permian fauna in that area. The question at issue is: Do the higher invertebrate-bearing beds of the Kansas section represent Permian time? On the assumption that such is the case, a comparison of the evolution of the faunas of the two continents is interesting. Let any one acquainted with our eastern faunas look over Trautschold's monograph on the Moscovian fauna and he would exclaim at once, "This is our Pennsylvanian facies." Let him next examine Tschernyschew's monograph on the Gschelian brachiopods, and he would find that nothing at all comparable is known among the faunas of eastern North America. He would even find that the few Pennsylvanian species which Tschernyschew has recognized among the Gschelian brachiopods are wrongly identified. If he furthermore studies the scattered accounts of the Artinskian and Permian faunas I think, too, that he will find less resemblance between them and the Kansas Permian than has often been supposed.

Apparently there was a basal generalized type of Upper Carboniferous fauna distributed over both continents without any wide difference of facies—the Moscovian of Russia, the pre-Hueconian of western North America, and the early Pennsylvanian of eastern. Then changes occurred which brought about striking and similar modification in the faunas of western America and Russia, the Gschelian of Russia and the Hueconian of western North America. Then again other changes occurred which brought about a third modification, this time restricted to western America, or, at all events, not developed similarly there and in Russia. Meanwhile the fauna of

eastern North America must have remained essentially static until similar conditions, setting in in Perm and in Kansas, eventually extinguished those already moribund faunas, while the intervening faunas, those of western America, remained vigorous and rich. The considerable differences found between the Russian Permian and the Kansas Permian faunas would, according to this hypothesis, be explained as due to the play of like conditions upon unlike organic bases, the pre-Permian faunas in the one region having changed, and those in the other having remained unchanged. But this appears to me improbable. One would hardly expect that the Pennsylvanian fauna would remain static during so long a period in which such important faunal changes were taking place in adjacent areas. Nor would one expect that Permian conditions would be inaugurated simultaneously in two areas so far apart, whose biologic histories are so different, and which were separated by an area having a more or less independent set of faunal phenomena. Finally, if the Kansas Permian is Permian, what is the fauna from the Oklahoma red beds, obtained at a considerably higher horizon, and showing a considerably different facies? It does not seem probable to me therefore that the Kansas Permian and the Russian Permian were contemporaneous.

An extreme interpretation of the resemblances and differences noted in comparing the successive faunas of Russia and eastern North America would result in correlating the Kansas Permian not with the Russian Permian, as in the last hypothesis, but with the Moscovian. In this case the quasi-Permian facies of the upper beds of Kansas would be accounted for as showing the yield of an unlike and older fauna to Permian conditions which arrived on this continent at a much earlier period than in Russia, just as in the previous case the *differences* of the same fauna from the typical Permian would be explained as the opposite or complementary phenomenon, the resistance of an unlike fauna to Permian conditions. Probably the ultimate fact lies somewhere between these two extreme interpretations of the evidence.

I do not wish to appear as having a rooted aversion to admitting the Permian age of the higher faunas of the Kansas section. My position is merely that of a skeptic and the only point upon which I feel justified in assuming the positive attitude of dogmatism is that

the evidence at present is so inconclusive that dogmatism itself would be ill-advised. At present, it is true, the weight of evidence, as presented by invertebrate paleontology, appears to me to be in favor of its pre-Permian age. This view has much of precedent against it, although it has considerable authority in its support. It will be remembered that some half century ago there was a conscious and competitive attempt between a number of invertebrate paleontologists to discover the presence of Permian rocks in our then western states. From this the correlation of the Kansas beds with the Russian Permian took its rise. I am inclined to believe that were the investigation of this subject taken up on its merits from the richer accumulations now available, and not compromised by this early rivalry, few if any would think of separating the upper formations of the series from the lower, or, if a separation were thought of, the divisions would be held rather to rank with the subdivisions recognized in the Mississippian than co-ordinate with the larger groups such Mississippian and Pennsylvanian.

At all events, it appears to me from such evidence as I have seen, that the Russian Permian represents peculiar, one may perhaps say abnormal, conditions which were probably local or regional in extent. That Permian time is represented by our sediments seems undoubted; that Permian conditions prevailed here is attested by good witnesses; that Permian conditions occurred here in Permian time seems to me open to question, and that any of our known faunas present the authentic Permian facies, I do not believe. Consequently the propriety of employing the term Permian in the geology of North America seems to me decidedly doubtful, at least in so far as the evidence of invertebrate fossils is concerned. It would be better, I believe, to use the term Permian wherever the Permian fauna can be traced and no farther; to use the term Pennsylvanian wherever the Pennsylvanian fauna can be traced and no farther; to use the term Guadalupian wherever the Guadalupian fauna can be traced and no farther; but, if, for instance, it could be shown that for all their faunal differences the Gschelian and Pennsylvanian were contemporaneous, to use for both the same name, whether Pennsylvanian or Gschelian, would be to obscure and gloss over facts of biology, climatology, and possibly geography, fully as important as that of chronology.

THE UPPER PALEOZOIC FLORAS, THEIR SUCCESSION AND RANGE[1]

DAVID WHITE

VII

CONTENTS

STRATIGRAPHIC VALUE OF LAND PLANTS

Diastrophism and floral changes.—The terrestrial plant is inseparably dependent on the conditions, not only of the soil and the water, but also of the air from which it derives an important part of its substance. Any change, therefore, in the climatic, terrestrial, or water conditions of its environment directly affects the plant and causes morphologic changes to a greater or less degree, the greater plant variations corresponding usually to the greater environmental changes. The great floral revolutions of geologic history are connected with the great diastrophic movements.

Sensitiveness of land plants to complicated environment.—The land plant, being essentially without the power of locomotion except by accidental dispersion of its progeny, is most vitally susceptible to changes in composition, temperature, etc., of its environmental elements. Accordingly it constitutes a most sensitive indicator of changes in these elements. The more highly organized the type the greater, in general, is its value as evidence either for identity of

[1] Published by permission of the director of the U. S. Geological Survey.

environment or for altered conditions. It must be admitted, however, that in the interpretation of the environmental criteria afforded by fossil plants, relatively little serious study has been given to anything other than climate. The ecology of the fossil floras is a new and almost unexplored department of paleobotany, though splendid work along certain lines was begun by Grand'Eury. The results of differences in soils or in altitude have received little attention. In general the conditions of fossilization naturally presuppose the origin of the vegetal forms at an elevation not far from that of the water-level beneath which they have, in most cases, been preserved, though here and there certain types have been regarded as drifted from higher altitudes.

THE DEVONIAN FLORAS

Probable origin of land flora in Devonian.—From the paleobotanical standpoint no period within the existence of land floras is of such imminent interest and yet is so little known as the Devonian. This fact is no doubt due mainly to the relative rareness of indubitably botanical material, its usually fragmentary condition, or its partial obliteration through metamorphism. Yet the Devonian period probably covers the early development, if not the actual beginning, of terrestrial plant life on the earth. It witnessed the origin of ferns, scouring rushes, Lycopods, and Gymnosperms, including the earliest relatives of the conifers. It is supposed to have given birth to the Pteridosperms, a group of seed-bearing ferns (Cycadofices), standing in the gap between the ferns and the Cycads.

Features of early land plants.—The development in early Devonian time of flat land surfaces and low coasts whose bays were bordered by broad marshes intermittently covered by brackish or fresh waters was most favorable for the nearly simultaneous development of a terrestrial habit in some of the highly varied types which then populated the seas. On some accounts it seems permissible to suppose that the ancestors of the land plants were amphibious, perhaps growing where exposed only at the recession of the tide. It is, I believe, probable that these early plants were but sparsely foliate, their leaves being either spinoid or very small, slender, and delicately thin. The latter were probably dorsally rolled at first during the

intervals of exposure to the air. The stomatiferous surfaces may have been very small for a time, and the stomata of periodic function only while the greater part of the carbonic-acid gas to serve as plant food was still drawn in the old way from the richly charged waters. The expansion of a proper leaf and the production of an aërial system of transpiration were presumably gradually evolved as the plant became weaned from its subaqueous habitat and accustomed to gain its food from an atmosphere which, it may be, was then better adapted to the nourishment of the emergent amphibian. However this may be it is fairly clear that the early representatives of the dominant Devonian types were of limited foliar expanse. Cuticular transmission of gases is still observed in the living ferns and Lycopods, the latter being far less susceptible to carbon-dioxide poisoning than are the higher plants.

It also appears that to support their weight in air a reinforced cuticle, later developed as a very thick and complicated cortex, was made to serve until a woody axis and, eventually, secondary wood should be fully produced by their descendants. From the characters of some of the fossils it seems probable that, unable to stand alone, they sprawled or clambered about on the ground or on other plants.

The mode of occurrence of their fossil remains usually in fresh or brackish water lagoonal or estuarine deposits, which are frequently ripple-marked, or even sun-cracked, may be regarded, though not without caution, as pointing out the conditions of their earliest habitats.

MIDDLE DEVONIAN

Characters.—The first Paleozoic land flora sufficiently known to make it eligible to the series of correlation discussions is that of the Middle Devonian.

This flora, whose apparent meagerness is perhaps due mostly to meagerness of information, is of strange and forbidding aspect. Its most characteristic types are Psilophyton, Arthrostigma, and Rhachiopteris of Dawson. It is also marked by the presence of Protolepidodendron, a primitive forerunner of the great lycopod group and, before reaching the Portage we find added Archaeopteris, together with the curious Pseudosporochnus, which may supply the missing fronds to the defoliated Caulopteris-like stems from Ohio and New York.

Place of origin.—Though eastern America has contributed most to our knowledge of this flora, it is probable that either the estuaries of northwestern Europe or the Arctic regions offered the conditions most favorable for its development. It extended both east and west in a high degree of unity. For example, the flora which occurs in the "Chapman" sandstone in Maine, and which is present in the gulf region of Canada, is largely the same as that of Scotland, at Burnot in Belgium, or in the Lenne shales of the Rhine Provinces. The flora from Barrande's *H-h*, stage at Hostim in Bohemia is nearly counterfeited in the upper Middle Devonian of New York. The route of migration between Europe and America was presumably by Arctic lands beyond the North Atlantic. Nothing that can be called a land flora is yet known from the Middle Devonian of the Southern Hemisphere.

UPPER DEVONIAN

Floral characters.—Evolution of forms and the advent of new types mark the Upper Devonian flora, which bears no evidence of any great climatic separation from the preceding. Pseudobornia, perhaps first of the Protocalamariales, Dimeripteris, Leptophleum, Barrandeina, and Barinophyton are characteristic. It is pre-eminently the stage of Archaeopteris. The Protolepidodendreae are developing along divergent lines to Cyclostigma and to the Carboniferous Lepidodendron, while Archaeosigillaria makes its rare appearance.

Place of origin and migration.—I am strongly inclined to believe that this flora received its greatest contribution from eastern America, or, perhaps, from the Arctic regions; in either event its migration was probably over boreal land; for it extends with remarkable identity from Pennsylvania to southern Europe and is partially present even in Australia. *Archaeopteris obtusa* and *A. sphenophyllifolia* of Pennsylvania and New York are *A. archetypus* and *A. fissilis* of Ellsmere Land, Spitzbergen, and the Don; while Barinophyton, a unique type from New York, Maine, and Canada, extends to the British Isles, Belgium, Queensland, and Victoria, where also is found *Leptophloeum rhombicum*, another American plant.

The Devonian woods present no annual rings to bear evidence of seasonal changes in temperature or intervals of prolonged drought.

THE CARBONIFEROUS FLORAS

MISSISSIPPIAN ("LOWER CARBONIFEROUS")

Characters.—The step from the Upper Devonian flora to that of the Mississippian (" Lower Carboniferous ") is marked by a floral contrast which, in some regions, is unexpectedly sharp though the warping of the Devonian floor to form the new Carboniferous synclines and the contraction of the seas naturally premise distinct climatic as well as other environmental changes. The new flora which lived in the restricted basins of the early Mississippian consists of Triphyllopteris, the broad, large-pinnuled Aneimites, the linear (*flaccida*) type of Sphenopteris, Cyclostigma, Eskdalia, and the acuminate Lepidodendra chiefly of the *corrugatum* group.

Lowest stage—Pocono.—The early Mississippian was a time of sea expansion; and in a number of distant areas, such as the northern part of the Appalachian trough, northern Alaska, the eastern Arctic, Scotland, and southern Siberia, the conditions at this moment were favorable for the formation of considerable coals.

Source.—Since the vegetation was presumably most luxuriant in these regions of coal formation, and since greatest evolution of forms attends most rapid and luxuriant expansion of a flora, we are perhaps safe in supposing that these are probably the regions of evolution of the flora as a whole.

Regional differences.—In this connection it may be noted that, either on account of land or marine barriers, or because the climatic conditions throughout the northern hemisphere may at the outset have been less uniform than in the preceding epoch, the different areas exhibit more or less distinct local floral differences. Thus in the Pecono of West Virginia and Eastern Pennsylvania where Triphyllopteris and the *corrugatum* type of Lepidodendron are almost without competition, the former achieved a remarkable differentiation far surpassing that known in any other area. In Nova Scotia, on the other, hand, the Horton series, which I regard as practically contemporaneous with the Pocono, contains the same Lepidodendra, accompanied, however, by Aneimites instead of Triphyllopteris. In both these regions the formations are in close relations with the Upper Devonian—in fact, probably in continuous sequence at one point or another. But the Pocono flora is apparently nearer to the Arctic

Alaskan where the same linear-lobed Sphenopteris forms are also present; the Nova Scotian affiliates more closely with the eastern. All the genera mingle in Arctic Europe and in Siberia, where Cyclostigma, probably of Arctic birth, has a good development. The Pocono flora may have connected by a more northern route with Europe, where Triphyllopteris sparingly mingles with the Horton Aneimites, which presumably migrated by the Northeast Arctic land bridge. It is possible, however, that some of the regional differences, especially differences in species, are due to lack of exact synchronism in the plant beds of these remote regions.

Middle Mississippian flora.—The basal Carboniferous floras are largely replaced in the middle Mississippian by a plant association which is more varied and of very different aspect. Where conditions were favorable for plant growth and preservation we find a flora essentially consisting of Rhacopteris (of Schimper, including Rhodea of authors), Cardiopteris, Asterocalamites (=Bornia), with *Lepidodendron volkmannianum*, and *L. veltheimianum*, accompanied by a gradually increasing group of Sphenopterids.

Source and distribution.—The middle Mississippian flora probably had its greatest development among the islands and estuaries of western Europe; at least it is best known in that region. From there it seems to have extended almost homogeneously to the eastward into Siberia and to the southeast, either through the Balkans, Persia, and the Himalayas (linking together its discovered occurrences), or possibly by a more southern route, to South Africa and Australia where the flora was largely identical with that in Siberia. The flora at Cacheuta, in Argentina, which though small is mainly composed of European species, presumably traversed the same route as that later followed by the Gangamopteris flora—that is the "Gondwana land." The middle Mississippian flora of the Appalachian trough is but little known, and for the most part is unpublished. Though less closely bound to that of Europe than are the corresponding Pennsylvanian floras its genera and a number of its species are present in the basins of Europe. I may add that the Megalopteris-bearing beds along the Mississippi River in Illinois, long ago credited to the Chester, are of upper Pottsville age.

Moderate uniformity of climate.—The members of this flora do not

attain the gigantic proportions nor the specific differentiation of their Carboniferous successors; yet the relative homogeneity and the great radial distribution of this flora argue for the absence of distinct climatic zones in the recent sense while the apparent lack of annual rings, so far as the woods have been specially examined, is opposed to the idea of seasonal changes.

Upper Mississippian. Probable greater severity of climate.—Our knowledge of the flora of the uppermost part of the Mississippian is too insufficient, both as to its composition and its geographical distribution, to permit any very definite conclusions as to its province and climatic environment. Some at least of the plants exhibit a limited foliar expansion and semi-coriaceous character suggestive of conditions far less favorable for growth than in the Pennsylvanian ("Upper Carboniferous"), or even in the early Mississippian. They seem to forewarn us of the great floral change which was, perhaps, already in progress. From this highest stage may have come *Dadoxylon pennsylvanicum*, the only wood from the American Carboniferous which appears on authoritative testimony to show annual rings, but whose geologic age is unfortunately recorded merely as "Carboniferous." Also it is possible that the *Araucarites tchihatcheffianus*, from western Siberia, said to have been found in the Carboniferous limestone series, may belong to the same horizon. The occurrence of severer climatic conditions with seasonal changes within upper Mississippian time is provisionally admissible; but it is probable that a radical climatic change attended the post-Mississippian elevation, the maximum variation being presumably marked by the climax of the uplift. The paleobotanical revival which set in at the beginning of the Pennsylvanian is known to all. Even in regions of supposed continuous Mississippian-Pennsylvanian deposition the contrast between the older and the younger floras (which do not really come in contact) is very strongly marked.

PENNSYLVANIAN ("UPPER CARBONIFEROUS")

The Westphalian

Environmental changes.—Following the retirement of the sea from great areas at the close of the Mississippian ("Lower Carboniferous"), the new land surfaces were warped into new forms, with the produc-

tion of additional as well as more complicated synclines. In these at first greatly restricted basins the sea began a great readvance, attended by the subsidence and deformation of the new basins under loading. These changes were most active during the Pottsville, the lowest of the American Pennsylvanian series. The new climatic and terrestrial conditions were most favorable to the extraordinary growth and differentiation of the plant life which spread across broad base-level plains and over the marshes and lagoons that flanked its long inland-reaching estuaries.

Appalachian deposition.—In the Appalachian trough the basin in earliest Pottsville time was confined to a very narrow estuary extending from the anthracite region of northeast Pennsylvania southward to Alabama where it became confluent with a small lobe of the sea extending northward toward southern Illinois and Indiana. Subsidence under loading was most rapid, with successive periods of sea advance to the north and west during all Pottsville time, at the close of which the water-level may have proximated its greatest Pennsylvanian extent; at least it exceeded the present limits of the coalfields.[1] The enormously expanded water-level of the Allegheny formation attended a westward migration of the axis of deposition, probably with the development of minor subordinate basins. Slight warping occurred during the period, especially to the southward, so that the connection with the Eastern Interior basin presumably migrated northward into the Kentucky region, foreshadowing the probable exclusion of the sea from the southern area of the present Appalachian coalfield during later Conemaugh and Monongahela time.

Rapid Evolution. Floral characters definite, with many short-lived genera in early Pennsylvanian.—The most rapid evolution of the Pennsylvanian flora occurred during Pottsville time, though the generation of new forms continued at a slower rate into the Allegheny, which, together with the Pottsville, approximately represents the Westphalian or Muscovian in North America.

The Westphalian is the period of Cheilanthites, Mariopteris, Diplothmema, Crossotheca, Eremopteris, Palmatopteris, Lonchopteris, Megalopteris, Lesleya, Neriopteris, Bothrodendron, Ulodendron, Lepidophloios, and Whittleseya, besides a number of genera repre-

[1] *Bull. Geol. Soc. Amer.*, Vol. XV (1904), p. 267.

senting filicoid types of fructification. One-half of these genera scarcely, if at all, survive the Pottsville. Three or four only outlive the Allegheny. The Westphalian witnessed the maximum development in Sphenopteris, Neuropteris, and Alethopteris, and of the great Lycopod group. It is pre-eminently the stage of the Cycadifilices.

Remarkable distribution of identical species.—The intercontinental distribution of the Westphalian plants is probably less remarkably uniform than is generally stated. The examination of the floras shows minor differences between the floras of different basins, as, for example, freshwater or marine basins in the same country, though many of these differences disappear as additional material is collected. Also different areas in the same basin, and, similarly, different horizons in the same basin may show predominances of Lycopods, or ferns, etc., or the apparent absence of certain genera. But as between the larger provinces, and taking the flora as a whole, from continent to continent, the number of genera not common, for example, to Europe and America, is so small as to excite special interest. The proportion of identical species is so large as to necessitate an extraordinary lack of barriers to the freest migration. The flora of the basin of Heraclea in Asia Minor[1] lends itself to ready correlation, stage by stage, with three corresponding formations of the Pottsville in the Appalachian trough; also, of the 33 species reported by Zeiller in a collection from the Westphalian of the Djebel-Bechar region of Persia, 25 are present in the Pottsville of the Appalachian trough.

The uniformity of distribution of the Westphalian flora complicates the geographical question of its origin. Taking therefore as most reliable the evidence of first appearances, we may note that Cheilanthites (including portions of Pseudopecopteris and Sphenopteris), Mariopteris, Eremopteris, Neuropteris, Alethopteris, and perhaps Pecopteris, were more highly differentiated in America, though Sphenopteris experienced a perhaps greater development in Austria and Bohemia. In Europe the Lycopods appear to have had greater advancement. Also, Cingularia, unknown outside of the freshwater basins of Germany, and Lonchopteris, largely confined thereto, have not yet been found in North America; while the unique genus Neriopteris is still unknown in Europe. On the other hand, the rare

[1] *Jour. Geol.*, Vol. IX (1901), p. 192.

genera, Lesleya, Megalopteris, and Whittleseya, apparently originated in America whence they spread northeastward. The same is true of the lower Pottsville Phyllotheca, which appeared a little later in Heraclea, and finally, in a new group of forms, became somewhat characteristic of the Gangamopteris flora of "Gondwana land." On the whole, therefore, it is probable that the Westphalian flora is the joint contribution of the lagoonal—i. e., coal-forming—regions of western Europe and eastern America. Free inter-communication was almost certainly by an Arctic land bridge, possibly by way of a Greenland-Scandinavian shore connection. The general regional distribution of the Pennsylvanian floras is shown in Fig. 1.

The Stephanian

Conditions of deposition and probable equivalents.—The Stephanian or Ouralian (including the Gschellian) of Europe dates from the Hercynian uplift. Prior to this movement the sea had reached its maximum extension in the coalfields of the northern hemisphere. The Hercynian thrust caused its practical expulsion from the old synclines of western Europe and the creation, especially to the southward, of new basins, mostly of fresh or brackish water, to which were transferred the scenes of coal-formation. In America the line between the Westphalian and Stephanian is not yet accurately drawn, the fossil floras being not studied in sufficient detail. In view, however, of the paleobotanical evidence indicative of a point near the Allegheny-Conemaugh boundary, I, personally, am inclined to regard the formation of the Mahoning sandstone (conglomeratic), the changed sedimentation of the Conemaugh formation, the probable upwarp of the southern Appalachian region which later resulted in the exclusion of the sea from the northern area also, and the consequent climatic changes, as due to the same great orogenic influence. Accordingly I would provisionally place the greater part, if not all, of the Conemaugh together with the Monongahela in the Stephanian.

The final exclusion of the sea from the Appalachian trough appears to have occurred soon after the deposition of the Ames limestone, near the middle of the Conemaugh, since, according to reports, only fresh, or possibly brackish water mollusca occur in the higher terranes.[1]

[1] I. C. White, *Report IIA*, Geol. Surv. W. Va., p. 622.

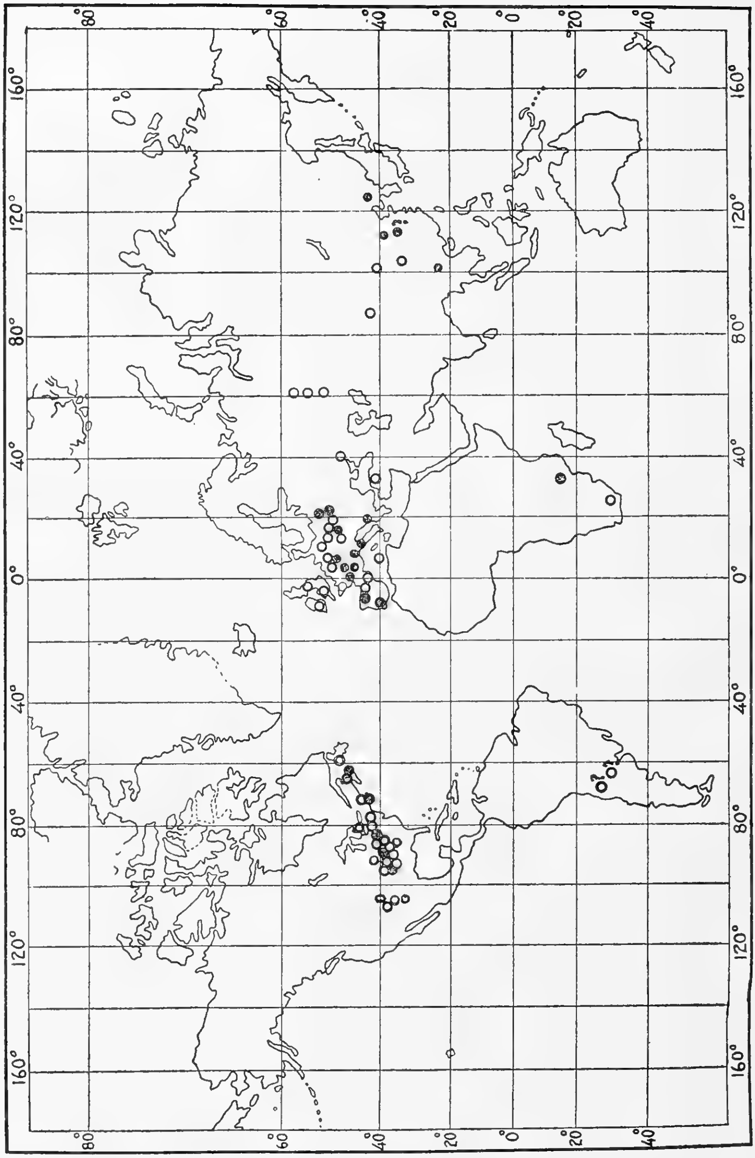


Fig. 1.—Regional distribution of Pennsylvanian ("Upper Carboniferous") floras. White rings = Westphalian plants; black rings = Stephanian plants.

It is probable that the Monongahela was never deposited in the southern Appalachian region, from portions of which the Conemaugh may also have been absent, the red oxidized sediments of the latter being in part derived, I believe, from the eroded unconsolidated older Pennsylvanian to the southeastward.

Floral characters.—The Stephanian is marked by the great development of Pecopteris, Callipteridium, and Odontopteris of the true type. It witnessed the nearly complete disappearance of Alethopteris, Sigillaria, and Lepidodendron. Neuropteris of the large-pinnuled forms enters its period of decadence. Before its close appear the first representatives of Callipteris, Walchia, Taeniopteris of the simple type, Pterophyllum, Zamites, and Plagiozamites, all characteristic of the Permian or later periods.

In eastern America, where the relations of land and water were but gradually altered and the sedimentation was continuous, the passage to the Stephanian flora has no line of sharp paleobotanical demarkation. The change appears to be gentle and the older forms drop out more slowly. In Europe, on the other hand, the contrast is a little sharper; the old types disappear more abruptly and many new ones take their places. A number of these new types have not yet been found in the Permian of this country. Among these are the four Permian coniferal and cycadalean genera above mentioned.

Source and distribution of the flora.—It is clear that the new elements of our Stephanian flora are chiefly, at least, of European origin, the plant life there having been directly influenced by the important physical changes to which it was immediately subjected. The various exotic types migrated to North America, probably, along or near the general route traversed by their Westphalian predecessors. Also, since the Stephanian flora of the American basins seems to afford no evidence of a rapid or strongly pronounced climatic alteration, it becomes fairly probable that the more abrupt plant changes described in western Europe were induced chiefly by the sweeping orogenic effects of the Hercynian movement, rather than by a great climatic change of world-wide extent. This does not, however, preclude a moderate but far-reaching modification of climate, in which changes in the atmospheric composition may have played a subtle if not important part. It seems hardly possible that the tremendous

amounts of carbon then being stored away in the coalfields as the result of plant extraction from the air could have failed to produce some effect on the atmospheric content of CO_2.

Though the Stephanian flora has less unity in its distribution than had the Westphalian, it is nevertheless remarkable for its geographical range. The flora reported by Zalessky[1] from the Yen-tai mines near Mukden in Manchuria embraces eight species, seven of which are found in western Europe, while six are present in the Appalachian trough. Or, looking southward, at Tete on the Zambesi in southern Africa, we find that all of eleven species reported by Zeiller are present in Europe and nine or ten, about 80 per cent., in America also. In harmony with these facts we find but slight traces of annual rings in the woods of the Stephanian, either in Europe or in America. This is the more noteworthy because the date of the Gondwana-land glaciation has been referred by various geologists to the Stephanian.

THE PERMIAN FLORAS

Floral characters.—The coming of the Permian is characterized not only by orogenic movements in the eastern hemisphere, but also by indications of increasing climatic differences. The first paleobotanical effect of these is the extinction of nearly all characteristic Carboniferous types, except in Pecopteris, Cordaites, and Neuropteris, the latter, however, disappearing nearly completely by the close of the Autunian or lower stage. They are replaced by varied forms of Callipteris, the lingulate Odontopteris and the ribbon-like Taeniopteris, together with expanding gymnospermous types, such as Walchia, Dicranophyllum, Doleropteris, Psygmophyllum, and Ginkgophyllum. Later, in the Saxonian, or Middle Permian, Voltzia, with the thick-leaved Equisetites, appears while more of the older types go out; and in the Thuringian, or Zechstein (Upper Permian) Rhipidopsis, Araucarites, Gomphostrobus, Voltzia, and Ullmannia, become the characteristic genera, while Pecopteris, dominant in the Stephanian, has nearly vanished. Though lacking the abundant Cycad and Cladophlebis-Asterocarpus elements, the Upper Permian is in many respects transitional to the older Mesozoic flora.

The Gangamopteris or lower Gondwana flora.—Meanwhile in the South a new flora, the Gangamopteris flora, or so-called Glossopteris

[1] *Verh. Russ. K. Min. Gesell.* (2), Vol. XLII (1905), p. 485.

flora, has arisen in the wake of retreating ice, though it is not really a glacial flora. It probably originated in a great region, the "Gondwana land" of Suess, from which the Stephanian flora had been more or less completely expelled by the rigorous climate, and to which it had not yet been able to return, presumably on account of either temperature or isolation.

The dominant characteristic types are Gangamopteris, Glossopteris, and its rhizome Vertebraria, Neuropteridium, Noeggerathiopsis, Phyllotheca, Schizoneura, Ottokaria, and Derbyopsis. The distribution and the relations of this flora to the Northern or Cosmopolitan flora have already been discussed in this journal.[1] The geographical extension of this flora in Paleozoic time, as also the distribution of the northern or cosmopolitan Permian flora, are shown on the Permian map, Fig. 2.

Distribution.—The uniformity of the Gangamopteris flora is so nearly complete as emphatically to indicate freedom of migration between all the areas in which it dominated; but whether Australia communicated with South Africa by way of India and Arabia, or by connection through an Antarctic land mass is a matter of opinion. The former is perhaps more probable. South America was almost certainly made accessible either to Africa or Australia by route over Antarctic land.

Gondwana climate.—The Gondwana climate following the glaciation was not too severe for the early return at distant points of a few of the presumably hardiest representatives of Psaronius, Sigillaria, Lepidophloios, and Lepidodendron, and at a higher stage, Voltzia Psygomophyllum, and Pterophyllum, both in Africa and South America. The early return of a climate not so widely different from that of the western Permian is further shown by the fact that though the early Gondwana woods found in beds more or less closely associated with the bowlder beds in Australia and South Africa show annual rings indicative of sharp seasonal changes, the woods from the higher portion of the series in South America show nearly continuous growth with but slight trace of seasonal differences.

Ability of types to mingle in later Permian and early Mesozoic environments.—This amelioration of temperature harmonizes, firstly,

[1] *Jour. Geol.*, Vol. XV (1907), p. 615.

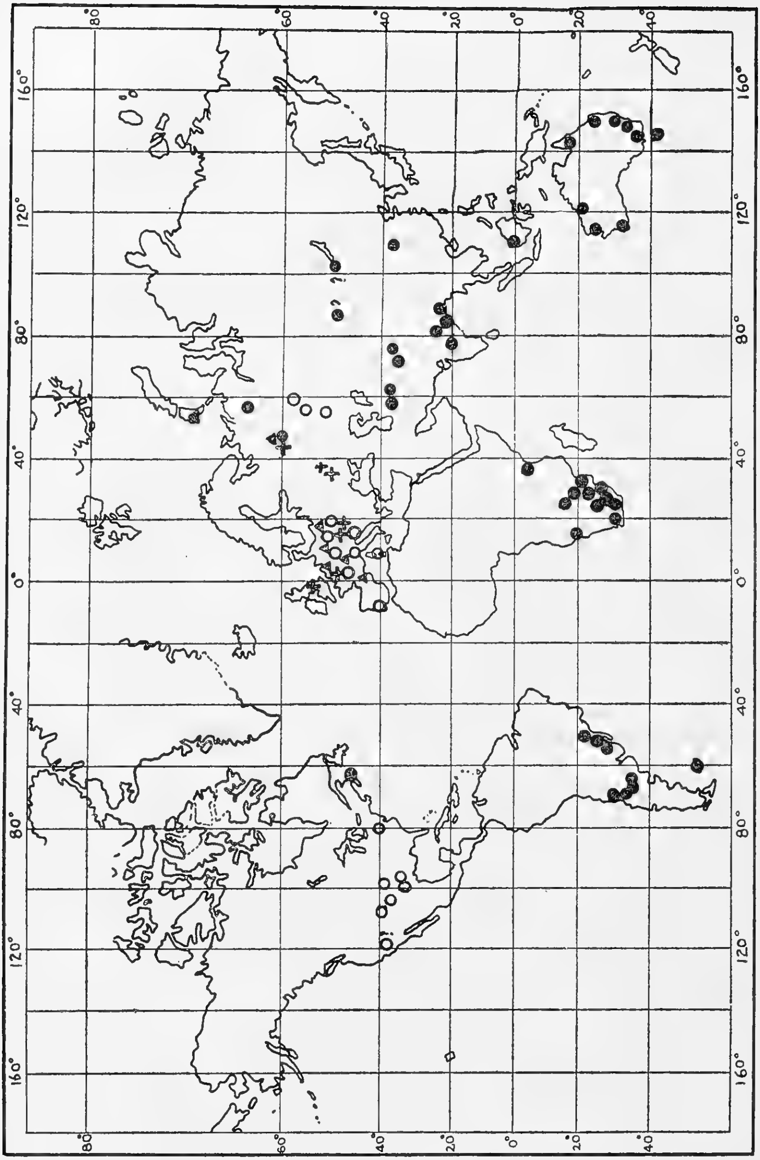


Fig. 2.—Regional distribution of Permian floras. White rings = Lower Permian; triangles = Middle Permian; crosses = Upper Permian; solid rings = Gondwana flora.

with the return of some of the northern types to portions of Gondwana land, and, secondly, with the fitness of some of the Gondwana types, especially Glossopteris, Phyllotheca, and Noeggerathiopsis, not only to join with Walchia and Callipteris in the Zechstein flora of northern Russia, but later to meet with Podozamites, Ctenophyllum, Cladophlebis, Clathropteris, and Dictyophyllum, under the mild climatic conditions of the early Mesozoic. Glossopteris, perhaps most adaptable of the older Gondwana types, was able to reach as far as the supposed Rhetic of Tonquin where it is last seen.

Glaciation.—It appears, therefore, that the interval, or better the *intervals*, of glaciation in Gondwana land were of relatively short duration as compared to all Permian time, though the thickness and distribution of the glacial deposits indicate a magnitude far exceeding that of Pleistocene glaciation. At the same time it seems improbable that refrigeration could have occurred in so many regions of the southern and eastern hemispheres, even approaching the equator, without some corresponding, though unequal, changes of world-wide extent. Concerning this very important point, the evidence is quite inconclusive and the opinions varied.

American Permian types derived from Europe.—If we compare the plants of eastern America with those of western Europe we find the greater changes in Europe where the extensive orogenic movements and attendant shifting of basins of deposition doubtless stimulated the evolution of the Permian flora. On the other hand, in the Appalachian trough, where environment was but little affected by orogeny, and where sedimentation was uninterrupted, there is only gradual change, many of the Stephanian types persisting far up in the Dunkard formation. The relatively few species characteristic of the European Permian which occur in the Dunkard, and which were not able to conquer the older flora under the conditions then existing, are clearly migrants from western Europe. It must be noted, though, that both West Virginia and Kansas exhibit new generic types, the products of local conditions, that have not been found outside of these regions. On the other hand, Walchia, which is present in Kansas and New Mexico has not yet been discovered in the Appalachian trough though it is present in the Nova Scotian basin, which seems to have been in closer touch with Europe at this time. The floral

changes in the western American areas, which are more pronounced than in the Appalachian trough, may be due either to changed physical conditions consequent to nearer and greater orogenic movements, or possibly to position nearer to the region of Gondwana glaciation. In our trans-Mississippi region the contrast between the Permian and Stephanian floras does not seem so sharp as that between the Ural flora and those, for example, of the fresh-water basins of France or England.

Greater contrasts in eastern Europe.—In France and in the Appalachian trough the early Permian floras are to a large extent identical, thus indicating continued freedom of intercourse. Also the woods present obscure rings or none at all. But in Kansas and Texas annual rings while still but slight are increasing in distinctness though many of the associated plants have a European distribution.

The plant fragments from the Permian of Nova Zembla are quite too insufficient to support the hypothesis of a far-northern route of intercontinental migration, or even to show that the climate of western Europe extended so far north.

Ural Mountains on western edge of a great climatic zone.—Indeed, on the contrary, the great scarcity of true Neuropterid and Pecopterid elements, the great development of Psygmophyllum, and the remarkable phases of Callipteris observed even in the Artinsk of the Ural region indicate, in my judgment, either temporary isolation or an appreciable difference in climatic conditions. At the same time the somewhat unique forms of Odontopteris are not without representation both on the central plateau of France and in the Wichita of Texas. This testimony of migration is supported by the supposed land relations, which, if Lapparent is correct, should have been particularly favorable for such a migration during portions of Permian time.

Extension of Gondwana flora into northern Asia.—Eastward of the Ural Mountains the floras of the Altai and headwaters of the Yenesei and in northern Mongolia, though provisionally referred to the Permian on account of the presence of Rhipidopsis, mingled with other types, including some of Gondwana facies, are possibly wholly lacking in specific types characteristic of the Cosmopolitan Western Permian. Though the stage of these plant beds is not yet fixed on

account of the strange character of the flora, I am inclined to regard the peculiar floral association as due to the extension of the early Gondwana climatic influence into north-central Asia and the subsequent isolation of the flora from western influences. This theory is supported by the presence of the older Gondwana flora in the coalfield of Shensi in China. On the other hand the floral differences between the Ural and eastern localities may be due to geographic position of the latter in the interior of the great Asiatic continent while the Ural flora which has more elements in common with the western world is located on the west coast of this continent.

The contrast is certainly not due to mere latitude, nor can it be credited wholly to aridity; for the eastern plants are associated in great series with coals in each region. A few stray wood fragments of uncertain location and age appear to offer slight evidence of seasonal changes, but the criteria deserve careful re-examination both as to this point and as to the geological horizon of the material described.

It would be most interesting to know to what extent the plant life of Permian time on the west coast of North America was influenced by the Gondwana glacial climate and as to how far it was allied to the older Gondwana floras.

The sharp contrast between the Chinese Gondwana plants and the floras of the very latest Stephanian in the same region involves a pronounced break either in climate or in time in that quarter of the globe. Probably both are concerned. The most satisfactory illumination of the stratigraphical and paleontological history of this period will probably be found in China or southern Siberia.

"PERMO-CARBONIFEROUS CLIMATES"

Climate of the Carboniferous.—The climate of the Pennsylvanian ("Upper Carboniferous") as viewed in perspective was mild and relatively humid, and, above all, equable over the greater part of the earth. It was moderate in temperature, not tropical, possibly not even subtropical, but, during the Westphalian at least, always and everywhere equable. It was truly temperate. The criteria which may be interpreted in support of this generally accepted proposition include:

1. The tremendous size and great height of the types, and their rank foliar development, indicating favorable conditions of environment and vigorous nutrition.

2. The succulent nature of many of the forms, the large size of the vessels and cells and the relatively great proportion of soft tissue, all indicating rapidity of growth in a moist, mild climate.

3. Spongy leaves suggestive of a moist atmosphere, and abundant and large intercellular spaces, as in the Lycopods, pointing to rapid moisture loss; also water pores for disposal of excess of moisture.

4. Stomata placed in grooves, as in the Lycopods, as if to prevent obstruction by falling rain.

5. Absence of annual rings in the woods; hence absence of marked seasonal changes.

6. The analogies of the present day show that aërial roots, so prominent in many of the Carboniferous types are characteristic of moist and tropical climates; that the nutrition—i. e., the decomposition of CO_2—is most rapid and the consequent growth also greatest and most rapid where the light is not too strong; that the ferns and Lycopods, so abundant in the Paleozoic, usually avoid bright glare. The same types are able to withstand larger amounts of CO_2 with benefit to themselves.

7. The nearest living relatives of the Paleozoic vascular Cryptogams reach their greatest size in humid and mild or warm climates. The successors of the marratiaceous, and gymnospermous types are now mostly confined to tropical or subtropical regions. The cycadalean stock, now characteristic of the same zones, was actually present in the upper coal-measures.

8. The formation of great amounts of coal indicates a rank growth, but in a temperature not so warm as to promote decay beyond the limit of rainfall protection.

9. Living nearest representatives of Paleozoic fishes now inhabit the estuaries of warm countries; while the nearest relatives of the Carboniferous insects are now found in mild and moist habitats.

10. The most forcible argument, after all, for an equable and uniform climate lies in the extraordinary geographical distribution of the floras in relative unity over the face of the earth. Humidity must naturally have attended such equability, extending, without

distinct terrestrial climatic zones, possibly completely into the polar regions.

Some of the criteria above mentioned are susceptible of different interpretations; but taken collectively they appear to admit of but one conclusion. Whether or not we admit that climatic changes may be caused by reasonable or practicable changes in the amount of carbonic-acid gas in the air it is certain that in geological times the vegetation of the earth must have been more or less influenced by the constitution of the atmosphere from which the plant derives so important a part of its real food.

Gradual loss of uniformity of climate, with brief glacial interruption in Permian.—As has already been indicated the Westphalian probably witnessed the greatest extension of uniformity and equability of climate over the earth. In the Stephanian the flora is hardly so homogeneous, though the world-climate appears still to have been so equable as to allow free migration of the larger part of the flora from a moderate latitude on one side of the equator to the opposite without encountering seriously obstructive seasonal changes. In the Permian the regional distinctions between the floras are much clearer; and presently climatic zones, and consequently botanical provinces, are recognized. Yet, about the North Atlantic the climate of the Lower Permian was still relatively uniform so that moderately free migration of the floras without the development, so far as we know, of pronounced annual rings, took place in the Autunian of France, the Permian of Prince Edward Island, the Dunkard of southwestern Pennsylvania, the Chase of Kansas, and the Wichita of Texas.

Red beds and climate.—It will be remembered that the period now considered is characterized in western Europe, England, Eastern Canada, the Appalachian trough, and the Western Interior basin, by the deposition of red beds which in some areas carry deposits of gypsum, etc., and which are generally regarded as laid down under an arid climate. Viewing the matter from the paleobotanical standpoint, we may ask whether equability and uniformity of climate, such as is shown by the fossil floras, is compatible with aridity in latitudes so high as northern England and the Gulf of St. Lawrence. If all the regions of Permian red-bed deposition were arid it would seem that humidity could not have been essential to equability of climate.

Coal-formation in Permian.—The lower Permian of Germany, France, Russia, and Pennsylvania, is commercially coal-bearing, while the Permian red beds of Kansas and Texas carry thin coals. Professor C. A. Davis informs me that in the United States today the formation of peat, the first stage of coal, is practically confined to the zone having twenty inches, or more, of rainfall.

Flora in red beds not perceptibly different from that in other sediments.—The plants in the Monongahela and Conemaugh do not seem to differ in kind whether the series are gray and limestone-bearing in Pennsylvania, or red and nearly devoid of limestones seventy-five miles to the south in West Virginia; except that although sometimes fairly abundant, they are very difficult to find in the red shales because the carbon of the plants is almost or entirely gone, as the result of destructive decomposition, only impressions of the leaves being left. Is it not possible that, in some instances, the causes of red-bed deposition lie to a large extent in relatively slow subsidence of the basin, and in differential warping to permit exposure, with some redeposition and dehydration? It is probable that there was aridity in certain regions and during certain intervals of the Permian; but there was evidently enough moisture to produce most extensive glaciation, and, later, to promote the formation of coals over broad areas in the great fresh-water Gondwana series laid down on the continents of South America, Africa, and Asia. The beds with the Gangamopteris flora are in most regions coal-bearing, usually commercially.

Date of glacial episode.—If one looks for climatic fissures, or dislocations into which to fit the relatively brief episode of Gondwana glaciation it is difficult either in western Europe, or in America, to find an opening between the base of the Westphalian and the top of the Lower Permian in which it may be fixed. It is true that, in most sections, we have intervals in which no plants are found; and, further, the lesson of Pleistocene deposition shows what sweeping climatic changes may occur and recur within a relatively insignificant thickness of strata. Yet, while the gap is often large enough in stratigraphical view, the plant-sequence so tightly closes it as to preclude a possible very distant exile of the flora for a time. We may therefore conclude that the glacial episodes probably occurred at the time of one of the orogenic movements; and, if so, preferably at one marked by the most

striking floral changes, since the effects of so important a climatic event must have been widespread.

If, therefore, the glacial interruption did not occur at the close of the Mississippian, as Bodenbender seems to see it, we may, I think, continue provisionally to regard it as occurring at the close of the Stephanian, or possibly (as would better suit many of the facts) as late as the middle Permian. The totally unaffected aspect of the topmost Stephanian flora near Mukden in Manchuria and in Italy, as well as of the somewhat earlier Stephanian flora in South Africa, would, if evidence of other kinds to the contrary were absent, tend somewhat strongly to prejudice in favor of the later date. The moderate temperature of the fairly equable "Permo-Carboniferous" climate in general may explain why the shock of the climatic episode was not more severely and for a longer time felt by the cosmopolitan Permian flora of western Europe and America.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

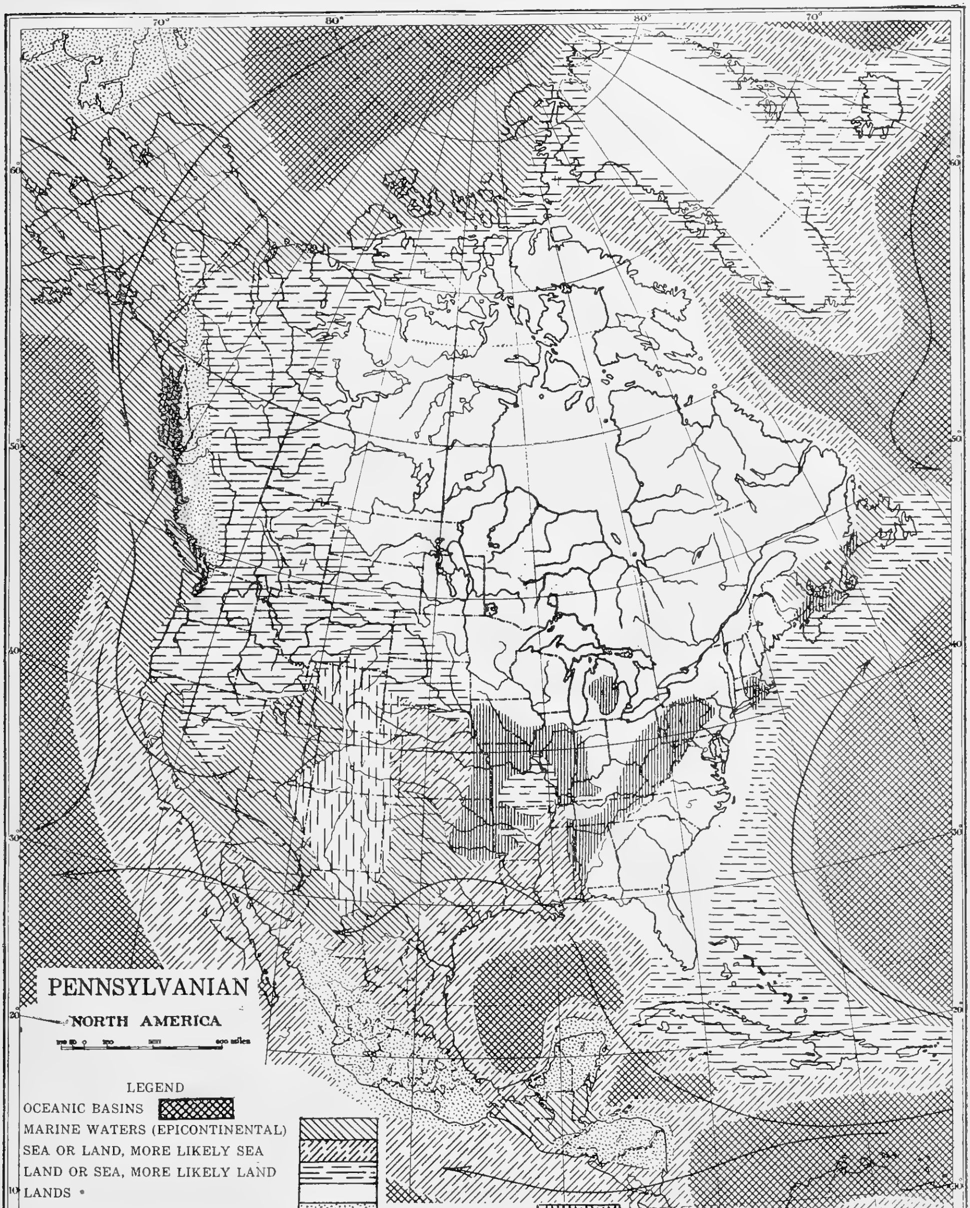
7. PENNSYLVANIAN NORTH AMERICA

The passage from Mississippian to Pennsylvanian was characterized by that emergence of lands, which is indicated on the map by the districts assigned to continental deposits and temporary lands. In the eastern United States the tendency toward emergence was progressive though interrupted. In the central west the emergence was but temporary and the transient land area was submerged under the Pennsylvanian sea. In contrast with the Mississippian, the Pennsylvanian continent probably extended far to the west—north of the fortieth parallel. As is shown by White there was land connection with England and Europe, probably around the North Atlantic.

The southeastern portion of the continent appears to have been embraced by branches of the equatorial Atlantic current. The northwestern part was washed by currents from the Arctic and north Pacific. The period was one during which climatic differences developed, and the situation of North America favored that development. The accumulation of coal in the southeastern portion in contrast to red sediments in the southwestern part may thus be explained as an effect of climate, in the one district favorable, in the other unfavorable to vegetation. Red beds are to some extent interbedded with coal measures, as glacial deposits of the Pleistocene are with interglacial, and it is probable that the relations may be interpreted as evidence of climatic fluctuations.[2]

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *Acknowledgments.*—The maps of Mississippian and Pennsylvanian North America were prepared in conference with Dr. G. H. Girty. As should have been stated in the appropriate connection, the maps of Devonian and Silurian geographies have been improved by data furnished by Dr. E. M. Kindle. The three earlier maps, particularly those of Cambrian conditions, are based on the work of Dr. C. D. Walcott, and have been adjusted to the results of his investigations. I am indebted to each of these scientists and also to many other fellow-geologists, members of the U. S. Survey and others, for suggestions courteously made. They are not responsible, however, for the drafts of the maps.—BAILEY WILLIS.


PENNSYLVANIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY LAND
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
120°
110°
100°
90°
80°
70°

THE CONVEXITY OF HILLTOPS[1]

G. K. GILBERT

In a maturely developed topography, hilltops composed of unconsolidated materials are upwardly convex in profile. Their forms are thus contrasted with the longitudinal profiles of stream beds, which in mature development are concave upward. An explanation of the river profile offered by the writer more than thirty years ago[2] seems to have been generally accepted. Its fundamental principles are (1) that the transporting power of a stream per unit of volume increases with the volume, (2) that transporting power increases with the slope, and (3) that a stream automatically adjusts slope to volume in such way as to equalize its work of transportation in different parts.

In 1892, Davis proposed an explanation of the convexity of hilltops, ascribing it to creep.[3] His article occupied less than a page of *Science*, and may not have attracted the attention it merited. At any rate Fenneman, in a recent discussion of the same subject, makes no mention either of Davis or of creep; and it occurs to me that a restatement of Davis' explanation may be timely.

Fenneman ascribes the convex profile to running water, making a distinction between the behavior of water near hilltops and lower down. As I find it difficult to do justice to his analysis in an abstract, I refrain from a comparison of his hypothesis with that of Davis, but refer the reader, instead, to his article which is in the *Journal of Geology* for November-December, 1908.[4]

The subjoined presentation of the creep hypothesis, while essentially equivalent to Davis', is independent in respect to various details.

A layer of unconsolidated material resting on a gentle slope holds its position (1) because the particles are arranged so as to support one

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *Geology of the Henry Mountains*, p. 116.

[3] W. M. Davis, "The Convex Profile of Bad-Land Divides," *Science*, XX, 245.

[4] N. M. Fenneman, "Some Features of Erosion by Unconcentrated Wash," *Journal of Geology*, XVI, 746–54.

another, and (2) because one particle cannot slide on another without developing friction. Spherical frictionless particles would flow on the faintest of slopes, and subangular frictionless particles would flow on a moderate slope. Whatever diminishes friction promotes flow. Whatever disturbs the arrangement of particles, permitting any motion among them, also promotes flow, because gravity is a factor in the rearrangement and its tendency is down the slope. Violent agitation by an earthquake suspends for the time the structural arrangement, surcharge by water greatly reduces friction, and each of these may cause flow, the flow phenomena being of the land-slide type.

In creep the chief disturbing agencies are expansion and contraction, and these are caused by freezing and thawing, heating and cooling, wetting and drying. If expansion were equal in all directions, and extended indefinitely downward, the arrangement of the particles —or the structure of the formation—would not be affected; but dilatation is resisted in all directions except outward, and expansion in a single direction modifies the structure. The structure is again modified during the ensuing contraction, and during both changes gravity enters as a constant factor tending downhill.

Prominent among other disturbing agencies are plant roots, which alike in growth and decay occasion soil movements; and roots also act on soils when trees are swayed by the wind. Animals promote creep in a more direct way, for as they walk either up or down a slope their feet push harder downhill than uphill.

Consider now the effect of creep on the law of slope. As we are speaking of mature topography only, we may assume the rate of degradation to be the same on all parts of the slope, so that the two lines in the diagrammatic section, Fig. 1, represent the surface of the ground at two epochs. In the interval between the epochs, there has been no transportation at the summit, D; but a volume of material equivalent to the prism enclosed by the lines between D and A has been carried past A; and a volume equivalent to the prism between

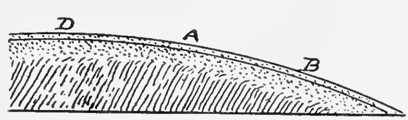


FIG. 1.—Diagrammatic section of a hilltop, indicating the zone of creep, and the position of the surface at two epochs.

D and B has been carried past B. The quantity passing each point of the slope has been proportional to the distance of the point from the summit. If the depth of the creeping layer has been uniform, the mean velocity of creep has been proportional to the distance from the summit. On the other hand the impelling force, gravity, depends for its effectiveness on slope, being able to cause more rapid flow where the slope is steeper. Therefore, on a mature or adjusted profile, the

FIG. 2.—Miniature hills, illustrating the convexity of divides and interstream ridges.

slope is everywhere just sufficient to produce the proper velocity. It is greatest where the velocity is greatest, and therefore increases progressively with distance from the summit. In other words the normal product of degradation by creep is a profile convex outward.

If soil creep and carriage by water are the only important processes of transportation operative in a region of maturely sculptured hills, the above analysis seems adequate. On the upper slopes, where water currents are weak, soil creep dominates and the profiles are convex. On lower slopes water flow dominates and profiles are con-

cave. Other factors may be mentioned, but it is probable that they acquire prominence only in special cases.

One of the mentionable factors is wind, which is no respecter of slopes, working as readily uphill as down. Another is rain beat. The two have this in common: that for each locality they have a dominant direction, so that any direct influence they may have on topographic expression tends toward asymmetry.

FIG. 3.—Miniature hills, illustrating the convexity of divides.

There is an indirect effect of rain beat due to its combination with water flow and this follows the direction of water flow. When raindrops beat heavily on the upper slopes there is usually also a diffused flow of water. Particles disturbed by the drops are momentarily suspended by the flowing water and drifted down the slope. Near the summit such transportation is favored by the shallowness of the water sheet but restricted by the slowness of the current. Lower down it is favored by more rapid current but restricted by depth of water, which lessens the effect of impact. Whether the ordinary result is greater transportation near the divides, tending to produce a convex profile,

or greater transportation on lower slopes, tending to produce a concave profile, is not easy to see.

As wind and rain beat are effective only on bare surfaces and surfaces imperfectly clothed by vegetation, while convex hilltops are found alike in forested regions, prairies and deserts, it is evident that their work is not of prime importance in this connection. Soil creep is omnipresent and appears to be competent.

Fig. 4.—Miniature hills, illustrating the convexity of divides.

The development of gullies on convex slopes when vegetal protection is removed, does not import a transformation to concave slopes and acute water partings, but merely a change in what Fenneman aptly calls the texture of the topography—a reduction of the scale of the drainage pattern and hill pattern. The removal of vegetation gives water flow greater velocity, thereby enlarging the domain of stream sculpture, with associated concave profiles, and reducing the domain of creep and convexity.

Figs. 2, 3, and 4 show mature hill forms developed in homogeneous material. They occur on the floors of hydraulic gold mines at

Nevada City, California. The washing away of the auriferous gravels laid bare tracts of decomposed granite in which the feldspars are largely changed to kaolin, and for about twenty years these have been exposed to the elements. There can be little question that here the convexities are due to creep; and the miniature topography illustrates strikingly the contrast between creep and stream work; but the conditions are not so near to normal as to make the forms fully repre-

FIG. 5.—Erosion and sculpture by the beating of raindrops. The material is regolith, exposed in a road cutting. The rain was driven by a strong wind so as to strike the ground in an obliquely ascending direction, from right to left.

sentative. The kaolin is so cohesive when wet as to tolerate slopes far above the "angle of repose," and this leads to an exaggerated expression of the convex profile, shown especially in Fig. 2; and in the other examples there is reason to believe that the positions of gullies were largely determined by shrinkage cracks.

Fig. 5 illustrates the power of raindrop impact to attack unprotected surfaces of waste. In ordinary examples of rain sculpture the

lesson is conveyed by the presence of pillars of earth each capped by a pebble or other protective particle, but it is not easy to determine whether the work of sculpture consumed little or much time. In this particular case the raindrops were driven by so violent a wind as to be swept *up* a slope. The wind in question blew for but a fraction of an hour, but in that brief time the rain beat developed on the earthbank (of regolith) a complete system of furrows and ridges parallel to the direction of the wind.

GEOLOGICAL SECTION OF NEW JERSEY[1]

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PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of New Jersey comprise certain white crystalline limestones with closely associated quartzites and conglomerates and a great complex of granitoid gneisses, pegmatites, and magnetites which, because of their resistance to erosion, underlie the Highlands of the state.

Franklin limestone.—The Franklin limestone in its more common phases is a white, highly crystalline, coarsely granular limestone or marble, ranging in composition from a nearly pure carbonate of lime to a dolomite. Some of it is rather siliceous and in a few places thin beds of sandstone have been noted. At Franklin Furnace and Sterling Hill it contains large beds of zinc ore and magnetite veins are also present in a few places. Graphite is widely disseminated in the limestone, and with mica, pyroxene, and chondrodite frequently gives the rock a gneissic structure.

The Franklin limestone is unconformably overlain by basal members of the Cambrian system. It contains intercalated masses of gneiss, and is injected by numerous bodies of pegmatite, neither of which rocks are associated with the Cambrian formation. On the other hand, the Hardyston quartzite, the lowest member of the Cambrian, locally contains fragments derived from these pegmatites, and even fragments of the coarse-grained limestone itself. That the Franklin limestone was metamorphosed to its present condition long before the deposition of the lowermost Cambrian sediments has been abundantly demonstrated.

The gneisses.—The gneisses appear in many varieties and of different sorts so intricately mingled that detailed representation of

[1] In the preparation of this paper, I have drawn freely from the published reports of my associates on the Geological Survey of New Jersey and of those workers on the U. S. Geological Survey who have dealt with the problems of this area. To Dr. A. C. Spencer, in particular, am I indebted for data on the pre-Cambrian rocks.

their distribution on geologic maps is quite impracticable. The most noteworthy differences of appearance presented by them are those of color, and inasmuch as color-distinctions have been found to correspond broadly with fairly definite lithologic differences, they may be used as a guide in classifying the gneisses for the purposes of description and mapping.

All the dark gneisses which owe their color to the hornblende, pyroxene, or biotite which they contain have been grouped together under the name Pochuck gneiss. The second group, the members of which show brown-gray, bronzy, pink, and ocherous tones, is called the Byram gneiss. Here are included a great variety of granitoid or granite-like rocks related to one another and distinguished from the other gneisses by the presence of potash feldspar as an essential ingredient. A third group, the Losee gneiss, includes light-colored granitoid rocks, many of them nearly white, which contain lime-soda feldspar as an essential and characteristic mineral component.

These varieties of gneiss are seldom found in large masses free from intermixture with other sorts, but the different facies or varieties occur in tabular masses which are interlayered both on a large and on a small scale.

These gneisses, with few exceptions, correspond accurately in their mineralogical and chemical composition with common types of coarse-grained igneous rocks like the granites and diorites. The light-colored granitoid rocks included under the names of Losee gneiss and Byram gneiss are present in the largest amounts. There can be little doubt that they solidified in part out of invading silicate solutions or molten magmas. Evidence of crushing in the minerals of these gneisses is almost entirely wanting, and appearances strongly favor the belief that the gneissic foliation is original in these intrusive rocks of the pre-Cambrian complex.

The dark Pochuck gneisses have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals, or, as is believed, in part from both, their present characteristics have in most places been acquired by metamorphism, involving secondary crystallization. Foliation is everywhere present in these dark rocks, and parallel to this structure they are injected in all proportions by sheets of light-colored material

similar in composition to phases of the Losee gneiss. They are also interlayered with both the Losee and Byram gneisses on a broad scale, and the Franklin limestones are similarly interlayered with the granitoid gneisses, so that these two sets of rocks—the dark Pochuck gneisses and the Franklin limestones—together seem to constitute a matrix holding the intrusive granitoid rocks in the form of relatively thin but extended plates.

Though the Pochuck gneiss and the Franklin limestone are both regarded as older than the granitoid gneisses, the original relations between them are not determinable.

Apparently the dark rocks were already foliated before they were invaded, because the interlayering of the granitoid materials is so regular that the presence of some structural control would seem to have been a necessity, but during this deformation the early texture of the rock was broken down, important addition or subtraction of elements may have occurred, and a later crystallization ensued contemporaneous with the crystallization of the injected material. The forces causing flowage probably continued to operate after crystallization had begun, and practically until it was complete, so that the injection of the granitoid material, the pressing out and kneading of the masses of the matrix, and the development of textural foliation in both were phenomena connected in origin with a single cause.

The Franklin limestone locally retains traces of original stratification, showing its sedimentary origin, but the lamination observed within masses of this rock is regarded mainly as a sort of flow structure developed through the crystallization of the limestone masses while they were being molded under the action of deforming stresses and at the same time traversed by mineral-charged waters derived from the invading Losee and Byram magmas. The facts are believed to warrant the conclusion that the white limestones and the various gneisses with which they are associated, together with the ore-deposits which they inclose, crystallized in their present state and received their present forms as geologic masses during a single period of regional deformation.

PALEOZOIC FORMATIONS

The Paleozoic rocks comprise representatives of the Cambrian, Ordovician, Silurian, and Devonian systems. They outcrop (*a*) in a

few small areas southeast of the Highlands between the pre-Cambrian crystallines and the Mesozoic strata, (*b*) in narrow valleys within the Highlands, (*c*) in a board belt northwest of the Highlands, the latter area comprising the northern extension of the great Appalachian valley and the mountain west of it.

CAMBRIAN SYSTEM

Hardyston quartzite.—The Hardyston quartzite is the lowest formation of the Cambrian system, and is probably to be correlated with the Poughquag quartzite of Dutchess County, N. Y., and the Chickies quartzite of Pennsylvania. It is unconformable on the pre-Cambrian complex and is the oldest fossiliferous rock in New Jersey. It varies considerably in composition and thickness. Typically it is a quartzite, at many places conglomeratic and containing pebbles of quartz, feldspar, granite, gneiss, and slate. Locally the formation is a calcareous sandstone. It is usually but not invariably feldspathic. In some localities its arkose character is so marked that it is not readily distinguishable from a coarse granite. Beds of slate occur in its upper portion.

Its thickness ranges from a few feet to 200 or more, and it passes into the overlying sandstone through slaty or shaly layers, several of which are in places interbedded with limestone layers, so that its upper limits are indefinite. Since it contains a species of Olenellus, it is regarded as of Georgian (Lower Cambrian) age.

Kittatinny limestone.—The Hardyston quartzite grades upward into the thick magnesian Kittatinny limestone of the Kittatinny Valley. Above, it is limited by an unconformity at the base of the Jacksonburg (Trenton) limestone. The presence of thin shales and scattered seams of sandstone in the great mass of limestone shows an influx of land sediments at recurrent intervals during its formation.

The known fauna of the Kittatinny limestone is not extensive and is found at but few localities, but it suffices to establish the Cambrian age of the greater part of the formation. No Middle Cambrian fossils have been found, but as the Olenellus fauna of the Hardyston quartzite is considered to be of Lower Cambrian age, and as no evidence of a break in sedimentation has been observed, a Middle Cambrian fauna would naturally be expected between the Olenellus

fauna below and the Dikelocephalus fauna above. In one locality a fauna of Ordovician (Beekmantown) age has been found in beds near the top of the Kittatinny limestone. This formation, therefore, where complete, represents a period extending from the middle or upper part of the Lower Cambrian to the lower part of the Ordovician, inclusive.

ORDOVICIAN SYSTEM

In northern New Jersey, as elsewhere in the great Appalachian valley, there is no sharp line of demarkation between the rocks of the Cambrian and those of the Ordovician system. The base of the Ordovician lies somewhere below the top of the Kittatinny limestone, as stated above, but the exact position of this division line cannot readily be determined.

Jacksonburg limestone.—Above the Kittatinny limestone, and separated from it by a break in sedimentation indicated by a calcareous basal conglomerate, is a dark-blue or black fossiliferous limestone, correlated with the Lowville, Black River, and lower Trenton limestone of the New York section and hitherto classed as "Trenton," some layers of which contain as much as 95 per cent. or more of calcium carbonate. Calcareous shales occur interbedded with these limestones and above them to the top of the formation. The sequence of conglomerate, limestone, and shale is a variable one, but, so far as observed, the transition to the overlying formation is always through a series of calcareous shales which become less and less limy.

The thickness of the Jacksonburg formation varies from 135 to 300 feet or more. It contains an abundant fauna, ninety-eight forms having been described by Weller. At the type locality the lower strata for a thickness of fifty-eight feet carry a Lowville–Black River fauna, and the higher beds have a lower Trenton fauna.

Martinsburg shale.—The Jacksonburg limestone passes upward through the calcareous shales mentioned above into a great thickness of shale, slate, and sandstone, which has heretofore been known as the "Hudson River slate," but which is now correlated with the Martinsburg shale of West Virginia and takes that name.

The formation ranges from the finest-grained shale and slate to fine sandstone. The former beds on the whole are black and more abundant in the lower part, whereas the sandstone beds are dark

bluish-gray, many of them calcareous, and occur more commonly higher in the formation. The fine-grained rocks exceed the gritty beds.

Slaty cleavage is the predominant structure of the fine-grained beds, and the true bedding planes are in many places difficult to determine. At some horizons the planes of cleavage are so straight and parallel and the rock so even textured that commercial slates have been obtained in considerable quantities. The whole formation is so crumpled and cleaved that no accurate estimate of its thickness can be made, but it is probably at least 3,000 feet, and it may be more.

Four species of graptolites characteristic of the Normanskill fauna of New York have been found in the lower portion of the Martinsburg shale, so that the beds in which they occur are equivalent in age to the middle portion of the typical Trenton limestone of central New York. A few miles north of the New Jersey state line, Schizocrania and graptolites characteristic of the Utica shale of the Mohawk Valley have been found in beds close to the overlying Shawangunk conglomerate.

SILURIAN SYSTEM

Contrary to long-prevalent, and apparently well-established belief, the lower and middle portions of the Silurian system are not represented in New Jersey. Their absence in this and adjoining regions is indicative of somewhat widespread earth movements unaccompanied in this region by folding, which closed the period of deposition indicated by the Martinsburg sediments or possible overlying beds afterwards removed by erosion and raised the region above the zone of sedimentation. When deposition began again late in Silurian time, beds of coarse conglomerate were laid down, followed by sandstones, shales, and limestones, the earlier sediments being those of a low-grade delta in an arm of the Appalachian gulf.[1] These conditions of deposition prevailed with but slight changes of elevation into Devonian time.

Shawangunk conglomerate.—The Shawangunk conglomerate (the Oneida conglomerate of many previous publications) is chiefly a

[1] Clarke, *N. Y. State Museum Bulletin 107*, p. 303.

coarse quartzite and conglomerate composed of small white-quartz pebbles imbedded in a siliceous matrix. Its color is generally steel blue, but some beds have a yellowish tinge, and reddish layers occur near the top. Layers of black shale a few inches in thickness are locally intercalated between thick beds of conglomerate and grit. Between this formation and the Martinsburg shale there is a gap representing the upper part of the Ordovician and all of the Silurian below the Salina of the full New York section, but there is no marked divergence of dip and strike where the two formations outcrop in proximity, and the actual contact is nowhere exposed in New Jersey. The beds overlying the Shawangunk conglomerate are red sandstone and shale, and the transition from the Shawangunk is made through a series of alternating red sandstone and gray conglomerate, so that the upper limit of the Shawangunk is not sharply defined. Its thickness is probably from 1,500 to 1,600 feet.

So far as known, the formation is barren of fossils in New Jersey, but at Otisville, N. Y., a euryterid fauna has been found in the black shale intercalated with the conglomerate. In the Otisville section this fauna, which elsewhere appears only and briefly at the base of the Salina, repeats itself many times through a thickness of 650 feet.[1] The Shawangunk conglomerate is followed by 2,500 feet or more of shales and limestones also referable to the Salina; hence for this region it represents only the lower portion of that group.

High Falls formation.—The red sandstone and shale which immediately overlie the Shawangunk conglomerate have until recently been regarded as the equivalent of the Medina sandstone of New York and have been so called, but, for the reasons just cited, it is evident that they are much younger than Medina and that they must be included in the Salina group. Moreover, they lie some distance below a limestone which is correlated with the Cobleskill of the New York section. The name High Falls has been applied to the red shales that overlie the Shawangunk conglomerate in Ulster County, N. Y., and has been adopted for New Jersey in place of Medina, which is not applicable.

The lower beds consist of a hard red quartzitic sandstone, intercalated with some green or gray sandstones and softer red shales

[1] Clarke, *op. cit.*, p. 303.

which become more abundant in the upper part of the formation. The formation has an estimated thickness of 2,300 feet at Delaware Water Gap. It is not known to contain fossils, but its age is fixed by its stratigraphic position.

Green Pond conglomerate.—The formation known as the Green Pond conglomerate occurs in an isolated belt of Paleozoic rocks which extends through the middle of the pre-Cambrian Highlands of New Jersey. In constitution it is similar to the Shawangunk conglomerate, with which it is correlated, but, inasmuch as it is still an open question whether the Paleozoic strata of the Green Pond Mountain region were once continuous with the great mass of Paleozoic sediments which lie some distance to the northwest, or whether the Green Pond region represents a separate basin shut off on the northwest from the large Paleozoic sea although communicating with it to the northeast, it has seemed best to retain for the present at least both Shawangunk and Green Pond as names for these conglomerates in their respective fields.

Longwood shale.—Immediately above the Green Pond conglomerate, and conformable with it, is a soft, red shale, in which an irregular cleavage is usually so highly developed that the bedding planes can be determined only with difficulty. The formation is not known to contain fossils, but, as it rests directly upon the Green Pond conglomerate and is followed by a limestone carrying a Salina fauna, it is probably of Salina age. Its stratigraphic position is, in general, the same as that of the High Falls formation, but the two may not be exactly synchronous.

FORMATIONS ABOVE THE HIGH FALLS AND LONGWOOD SHALES

The higher Silurian and the Devonian formations of New Jersey occur either in Wallpack Ridge, which lies along the northwestern border of the state in the upper Delaware Valley, or in the narrow belt of Paleozoic rocks in the midst of the Highlands in the Green Pond Mountain region. In Wallpack Ridge they aggregate 1,300 feet or more, while in Green Pond Mountain region they have a thickness of about 4,000 feet, of which all but 250 feet are referable to beds higher than any of those along Wallpack Ridge.

Poxino Island shale.—The top of the High Falls shale in New Jersey is everywhere buried by glacial drift which also conceals the beds immediately superjacent. The next recognizable formation is the Poxino Island shale, a buff or greenish calcareous shale in thin layers and non-fossiliferous so far as known. Its outcrops along the base of Wallpack Ridge in the upper Delaware Valley are few, small, and widely separated, and very little is known regarding it. In the adjoining portion of Pennsylvania it is reported to be 200 feet in thickness, and to rest on a thin limestone formation which in turn rests on the High Falls shale. It is not known to occur in the Green Pond Mountain region.

Bossardville limestone.—A fine-grained, compact, bluish-gray, banded limestone, known as the Bossardville limestone, lies conformably upon the Poxino Island shale in Wallpack Ridge. It increases in thickness from 12 feet at the New York state line to about 100 feet where it crosses the Delaware River into Pennsylvania. Owing to its marked banding it was for many years known as the "Ribbon" limestone and was correlated by Cook and later geologists with the Ribbon or Manlius limestone at Rondout, N. Y. In reality it lies below the Manlius limestone. It is only sparingly fossiliferous but is immediately succeeded by a series of beds containing a well-defined Salina fauna. It has not been recognized in the Green Pond Mountain belt, but this may be from lack of exposures.

Decker Ferry formation.—Under the name *Decker Ferry formation* a series of beds has been described, which are chiefly limestones at the north and calcareous sandstones at the southwest. Their thickness is 52 feet at the Nearpass quarry near Tri-States where the section can be accurately measured. Thin bands of more or less fissile green shale separate the limestone beds. A thin band of red, crystalline, highly fossiliferous limestone occurs about the middle of the series and is a striking feature. The lower 42 feet of these beds as exposed at the type locality are correlated[1] with the Wilbur limestone (the so-called "Niagara" or "Coralline" limestone of Hall and other authors) and the "black cement" beds, i. e., the Salina "water lime" of the Rondout section of New York. These form the top of the Salina group, the base of which in New Jersey is the base of the

[1] Hartnagle, *New York State Museum Bulletin 69*, p. 1152.

Shawangunk conglomerate. The upper ten feet of the Decker Ferry series contain fossils, particularly in the lower half, which render necessary their correlation with the Cobleskill limestone of eastern New York.

In the Green Pond Mountain region isolated outcrops of impure limestone occur a short distance above the Longwood shale, which contain a fauna that correlates them with the lower beds of the Decker Ferry formation, i. e., to the part referable to the Salina group.

Rondout limestone.—Along the upper Delaware the beds immediately above the Decker Ferry limestone and referred to the Rondout consist of more or less earthy shales and limestones the thickness of which is 39 feet. They are usually only sparingly fossiliferous, although in some beds the crustacean Leperditia is abundant. A typically marine fauna, with an abundance of brachiopods, trilobites, etc., is conspicuously absent in these beds. In general lithologic features this formation resembles the Rondout as developed in New York state, but the cement beds which are so characteristic of this formation farther north are not present here.

Manlius limestone.—The Rondout is succeeded conformably by a somewhat thin-bedded, knotty, dark-blue or almost black limestone, 34 to 35 feet thick where best exposed. It is the bed which constitutes the quarry stone of the Wallpack Ridge and its outcrop is marked by a line of quarries and lime kilns. It is referred to the Manlius or "Tentaculite" limestone of the New York series, although well-preserved specimens of the characteristic fossil *Tentaculites gyracanthus* Eaton are rare. In the lower beds there is evidence of evironmental conditions similar to those of the Rondout. In the middle portion, Leperditia is still abundant, but is associated with a prolific brachiopod fauna, suggestive of the recurrence of more typical marine conditions. In the upper beds Leperditia has entirely disappeared, and the fauna is normally marine. No beds referable to the Rondout or Manlius have been detected in the Green Pond Mountain region, although their attenuated representatives may occur.

THE DEVONIAN

The Devonian formations of the upper Delaware Valley are of marine origin and are chiefly fossiliferous calcareous shales and

limestones having a thickness of about 1,000 feet. Those of the Green Pond Mountain region are chiefly arenaceous shales, sandstones, and conglomerates, carrying comparatively few fossils, and aggregating over 4,000 feet in thickness.

The Helderbergian or lowermost Devonian faunas in New Jersey are essentially the same as those in New York, and the same faunal zones are recognized. The first formation carrying these faunas is the Coeymans limestone.

Coeymans limestone.—In the Nearpass section, the Coeymans limestone has an estimated thickness of forty feet, though only the lower beds are exposed. It rests conformably upon the Manlius limestone from which it differs lithologically in its coarser and more crystalline texture and lighter color. Frequently more or less chert is mingled with the limestone. The Coeymans fauna is far more prolific than that of the Manlius and differs markedly in composition, the most characteristic species being *Gypidula galeata.* A coral bed carrying more or less completely silicified masses of *Favosites helderbergiae*, and a concentrically laminated stromatoporoid occurs in the base of the formation.

Stormville sandstone.—In the southern half of the Wallpack Ridge in New Jersey, a thin sandy layer occurs at the top of the Coeymans limestone. It is in general an inconspicuous formation owing to its thinness and heavy deposits of glacial drift. It becomes more conspicuous toward the south and according to White[1] it gradually replaces the overlying calcareous and shaly strata until it occupies the entire interval between the Coeymans limestone and the Oriskany sandstone. It has not been recognized in the Nearpass section near Tri-States nor at any point north of Hainesville, N. J.

New Scotland beds.—The New Scotland beds which overlie the Coeymans limestone in the Nearpass section consist of about 20 feet of a very hard cherty limestone followed by a series of calcareous shales, having an estimated thickness of 140 feet. Nowhere in the state is there exposed a continuous section of these beds as is the case with several of the lower formations. The fauna is a prolific one, and is especially characterized by the abundant representation of the genus Spirifer. Its differences from the Coeymans fauna are of

[1] Second Geol. Surv. Penn., *Rep. G 6*, pp. 132, 133.

such an essential character as to indicate a separate immigration from the exterior into this region.[1] As indicated above, south of Hainsville, a thin sandy bed intervenes between the Coeymans limestone and the New Scotland beds and gradually replaces the latter. At Flatbrookville, where these strata cross the Delaware into Pennsylvania, the lower cherty limestone member of the New Scotland beds has disappeared, and the Stormville sandstone contains a fauna characterized by *Spirifer macropleurus*.

Becraft limestone.—A hard, gray, cherty limestone overlies the shaly layers of the New Scotland beds, forming a resistant layer which outcrops frequently along Wallpack Ridge. Its entire thickness has never been observed, but it is estimated to be about twenty feet. Its fauna is closely allied to that of the New Scotland beds, a few new forms appearing and a few old ones disappearing. There is also some difference in the proportionate number of individuals of some species, notably of *Leptaena rhomboidalis* which becomes especially abundant. The bed is correlated with the Becraft limestone of New York.

Kingston or Port Ewen beds.—A series of strata, nowhere exposed, occupies the interval between the Becraft limestone and the base of the Oriskany. They are probably shaly beds which easily disintegrate and thus become covered with débris. Their thickness is roughly estimated as eighty feet. The only basis for their correlation is their position which corresponds to that of the Port Ewen (Kingston) beds of New York. In Pennsylvania, the same beds have been called the Stormville shales by White.[2]

Oriskany formation.—A series of strata, aggregating about 170 feet in thickness, succeed the Port Ewen beds and are referred to the Oriskany. They are for the most part siliceous limestones, but the summit of the formation along the southern half of the Wallpack Ridge becomes a sandstone. The arenaceous facies is said to become more marked to the southwest in Pennsylvania and to embrace lower and lower beds until all the strata to the top of the Coeymans limestone are sandstones. The fauna of the Oriskany beds in New Jersey comprises three well-defined faunal zones, the lowest character-

[1] Weller, N. J. Geol. Survey, *Paleontology*, Vol. III, p. 90.

[2] Second Geol. Surv. Penn., *Rep. G 6*, p. 131.

ized by *Dalmanites dentatus*, the second by *Orbiculoidea jervensis*, and the third by the great abundance of *Spirifer murchisoni*.

In the Nearpass section the beds bearing the *Dalmanites dentatus* fauna are about 30 feet thick and form the crest of a high ridge which is the southern extension of the "trilobite ridge"[1] east of Tri-States. There is a mingling of Helderbergian and Oriskanian forms in this fauna, and there has been some difference of opinion as to whether these beds should be placed in the Port Ewen or Oriskany, but recent workers[2] unite in referring them to the Oriskany.

Esopus grit.—The Esopus grit which overlies the sandstones and siliceous limestones of the Oriskany forms the crest of Wallpack Ridge for the greater part of its extent in the state. It is a nearly black gritty rock with well-developed cleavage, which obscures the bedding planes. The fucoid "cauda galli" markings can frequently be recognized on the bedding planes when the latter can be distinguished. Apart from these markings fossils are very rare. The average thickness of the formation in New Jersey is estimated to be 375 feet.

Onondaga limestone.—The Onondaga limestone overlies the Esopus grit along the northwestern slope of Wallpack Ridge. Toward its base the formation is somewhat shaly and there is apparently a rather gradual transition from the grit to the limestone. The latter is hard, cherty, and regularly bedded in layers ranging from three inches to one foot in thickness. The beds are assigned to the Onondaga on the basis of their position and lithology rather than faunal evidence, since the recognizable forms are not sufficiently characteristic for close correlation.

Marcellus shale.—Fissile black shale, referable to the Marcellus, has been reported to occur in New Jersey along the bed of the Delaware River a few miles below Port Jervis, but in recent years the exposures have apparently been buried by silting-up of the channel. This is the highest of the Devonian beds exposed in the state along the Delaware River, but in the Green Pond Mountain area still younger beds occur.

[1] Shimer, *New York State Museum Bulletin 80*, pp. 175 f.

[2] Weller, Geol. Surv. of N. J., *Paleontology*, Vol. III, p. 96. Shimer, *op. cit.*, p. 184.

DEVONIAN FORMATIONS IN THE GREEN POND MOUNTAIN AREA

Kanouse sandstone.—The Kanouse sandstone, the lowest Devonian formation of the Green Pond Mountain region, is a thick-bedded, fine-grained conglomerate below, and a greenish sandstone above, having a thickness of about 215 feet. Although fossils are not rare, yet as a rule they are obscure, and many of them are so greatly distorted that their identification is impossible. So far as recognized they indicate an Onondaga fauna, and these beds may be interpreted as the shoreward correlatives of the Onondaga limestone. It is the formation which in the New Jersey Geological Survey reports has been called the Newfoundland grit.

Its outcrops form a narrow belt parallel to the Decker Ferry limestone, but separated from it by a narrow interval. In the upper Delaware Valley, as noted above, there are seven formations aggregating nearly 900 feet in thickness between the Decker Ferry and the Onondaga. In the Green Pond Mountain region none of these has been recognized and, if present at all, it can be only in very attenuated form.

Pequanac shale.—The Kanouse sandstone apparently grades upward into a black and dark-gray, thick-bedded, slaty shale (the "Monroe" shale of Darton and others). Cleavage is usually strongly developed so that the bedding planes are not always readily discernible. The thickness is estimated at 1,000 feet. This formation is probably conformable upon the Kanouse sandstone, but the contact has nowhere been observed. It contains a somewhat meager fauna among which, however, is the characteristic Hamilton species, *Tropidoleptus carinatus*, so that its reference to this period is beyond question.

Bellvale sandstone.—The Bellvale sandstone is scarcely more than a continuation of the Pequanac shale, but the beds are coarser and more sandy. The average thickness is estimated at 1,800 feet. The few fossils found are all Hamilton species.

Skunnemunk conglomerate.—The Bellvale sandstones grade upward into a coarse, purple-red, massive conglomerate, the white-quartz pebbles of which are sometimes 6 or 7 inches in diameter Beds of red, quartzitic sandstone alternate more or less frequently with the conglomerate and there are many gradations between the two. It forms the great mass of Bearfort Mountain in New Jersey

and of Bellvale and Skunnemunk mountains in New York. It is the youngest Devonian formation in New Jersey and rests upon beds known by their fossils to be of Hamilton age. Whether it is the exact equivalent of the Chemung-Catskill cannot be determined.

STRUCTURE OF THE PALEOZOIC FORMATIONS

The Paleozoic rocks have the northeast-southwest structure lines characteristic of all parts of the Appalachian province, due primarily to a system of folds and faults whose trend is in that direction. The folds are rarely symmetrical, southeastward dips being usually less steep than northwest dips, so that the axial planes are inclined to the southeast. The folding took place during the Appalachian revolution and is most marked in the beds farthest southeast and diminishes rapidly to the northwest. Some overthrust faulting occurred during the folding, so that now isolated masses of Kittatinny limestone rest upon the Martinsburg shale. The more conspicuous dislocations, however, are due to nearly vertical faults parallel or oblique to the axes of the fold, by which the northwest side has been usually uplifted relatively to the southeastern. These faults are referred to disturbances occurring at the close of the Triassic sedimentation.

TRIASSIC SYSTEM

The Mesozoic era is represented by formations referable both to the Triassic and to the Cretaceous systems. The Triassic rocks occupy a broad belt southeast of the Highlands and extend across the north-central portion of the state from northeast and southwest, their southeastern margin being approximately a line drawn from Trenton to Jersey City. They comprise both sedimentary and igneous rocks, the former chiefly shale, the latter extrusive basalt and intrusive diabase. They rest unconformably upon the early Paleozoics and pre-Cambrian crystallines and along their southeastern margin they are in part overlaid conformably by beds of Cretaceous age. The structure is monoclinal, the strata being inclined at low angles to the northwest, but locally broad, shallow folds have been developed. The beds are cut by many nearly vertical normal faults, the amount of dislocation varying from a few inches to several thousand feet. The rocks are sparingly fossiliferous, footprints of reptiles, a few

species of fish, and a small crustacean being the chief elements of a meager fauna.

Three divisions have been made on lithologic grounds: at the base the *Stockton* beds, comprising arkosic conglomerates and sandstones with some shales; above these the *Lockatong* beds, consisting of black shales, hard, massive, dark argillites, flagstones, and occasional very impure, thin, limestone layers; and at the top a great thickness of very soft argillaceous red shale, the Brunswick beds, which are more typical of the whole series than either of the other groups. Massive conglomerates at various points, chiefly along the northwest border adjoining the Highlands, replace these types at various horizons. Ripple marks, mud cracks, rain-drop impressions, reptile footprints are not uncommon in the finer shales, and cross-bedding, plunge and flow structure, and rapid variations of texture are characteristic of the coarser beds.

These sediments have been regarded as (1) deposits in broad shallow estuaries in which subsidence went on *pari passu* with deposition; (2) lake sediments; (3) sediments in orographic valleys made by rivers of enormous width; and (4) subaërial stream deposits on a piedmont plain fronting a newly uplifted crystalline foreland from which numerous short but vigorous streams derived the sediments which were deposited in coalescing alluvial fans. Occasional downward movements of warping or faulting gave opportunity for local thickening of the deposits along the belts affected. The latter view is perhaps the more likely, although the first still has its adherents.

Four or more periods of eruption at considerable intervals gave rise to three great sheets of basalt each of which is conformable to the beds on which it rests, and each of which was buried by continued sedimentation. The intrusion of a thick sill of diabase obliquely across the strata occurred toward the close of sedimentation. Uplift accompanied by northwestward tilting and normal faulting terminated the deposition of these beds, caused the displaced strata to be beveled off across the upturned edges, revealing the edges of the buried basalt and diabase sheets, and brought up again the crystallines which in adjoining states, and to some extent in New Jersey, skirt the southeast border. The constructional topography due to these orographic movements was largely, if not entirely

obliterated by erosion previous to the deposition of the Cretaceous sediments which overlap the beveled edges of the Triassic beds along their southeastern margin, and which formerly extended much farther northwestward than at present.

THE CRETACEOUS SYSTEM

The Cretaceous strata rest unconformably upon the beveled edges of the Triassic shales along their southeastern margin. They comprise unconsolidated sands and clays, which dip 50 to 25 feet per mile to the southeast, and which have an aggregate thickness of from 500 to 1,000 feet, the greater thickness being formed in the northern portion. The lowermost beds are referred to the upper part of the Lower Cretaceous and are of non-marine origin. The middle and upper portions, however, belong to the Upper Cretaceous and contain an abundant marine fauna.

Raritan formation.—The Raritan formation is extremely variable, consisting chiefly of light-colored sands and clays, some of the latter being highly refractory. There is on the whole a preponderance of clays in the lower and of sands in the upper half of the series. Since it was laid down on an irregular surface its thickness is variable, ranging from 150 to 250 feet at the outcrop, but increasing to the southeastward, as shown by well-borings, to over 500 feet. Northeast of Trenton it rests unconformably upon the beveled Triassic shales, but farther southward upon the ancient crystallines of early Paleozoic or pre-Paleozoic age, and perhaps at undetermined points still farther south on earlier Cretaceous beds. It dips 40 to 50 feet per mile to the southeast, the basal beds having the steeper inclination. The known fauna is very limited, consisting of a few pelecypods, some of which are brackish-water types while two are typically marine, a plesiosaurian bone, and possibly an insect. Its flora embraces a wide range of genera and species, especially of dicotyledons, many of which are closely related to modern forms. It has been regarded by Ward as late Lower Cretaceous and, therefore, approximately equivalent to the Gault of England.

Magothy formation.—The lignitic sands and clays referred to the Magothy formation and regarded as the lowermost of the Upper Cretaceous formations were until recently included in the Raritan.

On the shores of Raritan Bay they attain a thickness of 175 feet but diminish to the southwest and along Delaware River are only 25 or 30 feet. They are slightly glauconitic near the top. The Magothy rests unconformably on the Raritan but the discordance is not great and indicates only a slight epeirogenic movement. A marine fauna of 43 species, possessing close affinities to that of the Ripley beds of the south and to the Senonian of Europe, is found on the shores of Raritan Bay, but farther southwest the deposits are apparently estuarine. The flora is abundant and presents a much more recent aspect than that of the Raritan. It is regarded by paleobotanists as showing Cenomanian affinities.

Merchantville clay.—The Merchantville is a black, glauconitic, micaceous clay, usually greasy in appearance and massive in structure, weathering to an indurated brown earth. Its thickness is about 60 feet. It is conformable to the Magothy formation below and the Woodbury clay above. Its fauna is large and varied and although it contains many forms common to the beds above and below, its most characteristic species are conspicuous for their absence or great rarity in the adjoining strata. The Merchantville clay represents the lower part of the Crosswicks clay of Clark, forms the base of the Clay-marl series of Cook, and is the lowest of the five formations in New Jersey which are correlated with the Matawan formation of Maryland.

Woodbury clay.—The Woodbury is a black, non-glauconitic, jointed clay about 50 feet thick, which weathers to a light chocolate color, and when dry breaks into innumerable blocks, frequently with a conchoidal fracture. Its fauna of 95 marine species is more closely allied to that of the Magothy than to the subjacent Merchantville. It is conformable both with the Merchantville below and the Englishtown sand above. It is the upper part of the Crosswick clay of Clark, and forms part of the Clay-marl series of Cook. It is also one of the formations correlated with the Matawan of Maryland.

Englishtown sand.—The Englishtown is a conspicuous bed of white or yellow quartz sand slightly micaceous and sparingly glauconitic. Locally it contains thin laminae of fine brittle clay. So far as known it contains no fossils. It decreases in thickness from 100 feet near Atlantic Highlands to less than 20 feet in the southern portion of the state. It represents the lower part of the Hazlett sand of

Clark, and forms a part of Cook's Clay-marl series. It was formerly called the Columbus sand and is the equivalent of a part of the Matawan formation.

Marshalltown clay-marl.—The Marshalltown ranges from a black sandy clay to an argillaceous greensand marl. Locally it is abundantly fossiliferous, its characteristic species being in part recurrent forms from the Merchantville, and in part a new element, which recurs again in a higher formation although absent or inconspicuous in the immediately succeeding beds. Its thickness is 30 to 35 feet. It is a portion of the "laminated" sands which formed the upper part of the Clay-marl series of Cook, although in the southwestern portion of the state he referred these beds to the Navesink (Lower) marl. It was included in Clark's Hazlett sands, a subdivision of his Matawan.

The Wenonah and Mount Laurel sands.—Above the Marshalltown clay-marl there is a considerable thickness of sand regarding which there has been some difference of opinion. The terms Wenonah and Mount Laurel have both been applied to them in whole or in part. Lithologically they are not sharply differentiated from each other, although the lower part (Wenonah) is generally a fine micaceous sand and the upper part (Mount Laurel) is coarser and contains considerable greensand. Paleontologically, however, they are quite distinct. The Wenonah fauna is largely recurrent from the Woodbury, with comparatively few prominent species common either to the Marshalltown below or the Mount Laurel and Navesink above. The same elements are prominent again still higher in the Red Bank. The Mount Laurel fauna is identical with that of the Navesink above, and is closely allied to the Marshalltown, but contains a foreign element, chief among which is the cephalopod *Belemnitella americana* and the brachiopod *Terebratella plicata*, so that the indistinct lithological line between the Wenonah and Mount Laurel sands is of considerable paleontological singificance. The combined thickness of these formations is 40 to 80 feet, the Mount Laurel being limited to a very thin bed at Atlantic Highlands (Cook's sand-marl) but increasing much in thickness toward the southwest. The Wenonah sand is the highest bed correlated with the Matawan of Maryland, while the Mount Laurel is the base of the Monmouth.

Navesink marl.—The Navesink marl consists of greensand marl,

mixed with varying amounts of quartz sand and fine earth, the latter of which contains much carbonate of lime in a powdery state. Where purest the marl has a dark-green or bluish-black color. The upper part of the bed contains progressively less greensand and is more clayey. The fauna is large (121 species, Weller), and is allied with that of the Marshalltown and Merchantville beds, while the characteristic forms of the Magothy, Woodbury, and Wenonah are absent. The formation has a maximum thickness of about 40 feet, diminishing southward to 25 feet or less. It corresponds in general to Cook's Lower Marl, although locally beds referred by him to the Lower Marl have proved to be the Marshalltown. It rests conformably upon the beds below and grades upward into the Red Bank sand, or where that is absent into the Hornerstown marl.

Red Bank sand.—The Red Bank sand is for the most part a fairly coarse ferruginous yellow and reddish-brown quartz sand, locally indurated by the infiltration of iron. The lower beds are in many places somewhat clayey. The Red Bank fauna has come chiefly from these clayey layers. In its essential features it is a recurrence of the *Lucina cretacea* fauna of the Magothy, Woodbury, and Wenonah formations, and differs in important respects from the Navesink fauna immediately below. It occurs only in the northern part of the coastal plain where its maximum thickness is 100 feet, but it thins out and disappears midway across the state. It is the Red Sand of Cook and earlier writers but does not include certain sands in the southern portion which were correlated by him with the Red Sand of Monmouth County. With the overlying Tinton bed, it is the uppermost of the beds correlated with the Monmouth formation of Maryland.

Tinton bed.—A lense of green indurated clayey and sandy marl, having a thickness of from 10 to 20 feet, overlies the Red Bank sand in Monmouth County. Its fauna is more closely allied to that of the Navesink than of the Red Bank and is characterized by large numbers of crustacean claws of the genus Callianassa. It is Cook's "indurated green earth," regarded by him and other writers as a part of the Red Sand, but in view of its faunal and lithologic differences it deserves some separate recognition.

Correlation of the Magothy-Tinton beds.—The assemblage of fossils making up the faunas of the beds from the Magothy to the

Tinton inclusive constitute a larger faunal unit, much more sharply separated from the faunas above and below than are any of its constituent faunules from each other. Weller has shown that this larger faunal unit is made up of two or more distinct facies, one of which, the Cucullaea fauna, is characteristic of the more glauconitic beds; namely, the Merchantville, Marshalltown, Navesink, and Tinton, while the other facies characterized by *Lucina cretacea* or its associates occurs in the clays or clayey sands of the Cliffwood, Woodbury, Wenonah, and Red Bank formations. The two facies existed contemporaneously and migrated backward and forward across the present outcrop of these beds in New Jersey as deeper or shallower water conditions prevailed. The larger faunal unit is closely related to the Ripley fauna of Alabama, Mississippi, and Texas. On faunal evidence all the formations from the Magothy to Tinton inclusive are referable to the Senonian of Europe, although on floral evidence the Magothy might be regarded as Cenomanian.

Hornerstown marl.—The Hornerstown marl is a bed of glauconite with clay and sand and not differing materially from the Navesink. Its fauna is meager but is totally different in its essential characteristics from the faunas of all the underlying formations. *Terebratula harlani*, *Cucullaea vulgaris*, and *Gryphaea dissimilaris* (Weller) are characteristic forms. A shell bed at the top of the formation is a conspicuous feature at many localities. The thickness is 30 feet or less. At the north it rests with apparent conformity on the Tinton, where that is absent it lies on the Red Bank, and farther south it is continuous with the Navesink, owing to the disappearance of the Red Bank. It is conformably overlain by the Vincentown except where overlapped by Miocene formations. It is the Middle Marl of Cook, the Sewell marl of Clark, and is a part of the Rancocas group.

Vincentown sand.—The Vincentown sand presents two phases, a calcareous or limesand, semi-indurated, and largely a mass of broken bryozoan, echinoid, coral, and other calcareous remains, and a glauconitic quartz-sand phase. The two phases occur in alternating layers, although the former is more common in the basal portion, particularly to the south, while the quartz-sand phase predominates in Monmouth County. The fauna of the limesand phase contains large numbers of bryozoa, echinoids, and foraminifera, while in the

siliceous phase elements of the Hornerstown fauna occur in association with forms characteristic of the calcareous phase. Its thickness varies from 25 to 70 feet, but well-borings have shown that it thickens greatly down the dip. It rests conformably upon the Hornerstown marl and is overlain conformably by the Manasquan marl or overlapped by Miocene beds. It includes the "limesand" and "yellow sand" of Cook, the former of which was regarded by him as a part of the Middle Marl.

Manasquan marl.—The Manasquan marl in its lower portion (13–17 feet) is composed chiefly of glauconite, but the upper part (8–12 feet) is made up of very fine sand mixed with greenish-white clay, piles of which look like heaps of ashes—hence the name "ash marl." The fossils are not abundant and are poorly preserved, the commonest occurring also either in the Hornerstown or Vincentown. Its thickness is about 25 feet. It corresponds to the "green" and "ash" marls of Cook's Upper Marl bed and is the youngest of the Cretaceous formations exposed in New Jersey. It probably rests conformably upon the Vincentown and at most exposures is succeeded unconformably by Miocene or Pleistocene deposits, although locally it is overlain by a bluish marl of Eocene age without apparent unconformity.

Correlation of the Hornerstown, Vincentown, and Manasquan.—The faunas of these three formations are closely related, and form a larger fauna sharply separated from the Ripleyian fauna of the underlying Magothy and Tinton beds. This fauna has not been recognized south of Maryland. It shows certain affinities with the lower or Maestrichtian division of the Danian series of Western Europe (Weller).

EOCENE SYSTEM

Shark River marl.—Eocene deposits in New Jersey are limited in outcrop to small areas near Long Branch in Monmouth County where a mixture of greensand and light-colored earth 11 feet in thickness and carrying Eocene fossils rests without apparent unconformity upon the "ash" marl of the Manasquan. The conformity, however, is only apparent, well-borings indicating that the Shark River, as this formation has been called, probably overlaps the Cretaceous.

Clark[1] considers that it is not possible to correlate the Shark River marl with any other known Eocene deposits and regards them as probably older than the Eocene of Maryland. By some other authors, however, they have been placed above the Maryland Eocene.

MIOCENE SYSTEM

Beds of known Miocene age are widely distributed in the coastal-plain portion of New Jersey, where they overlap the Eocene and many of the Cretaceous formations. At the north they rest on beds ranging from the Eocene to the Hornerstown marl, while in the southern portion outliers are found upon the Mount Laurel sand.

Kirkwood formation.—Under the term Kirkwood have been included all beds of demonstrable Miocene age which outcrop in New Jersey. These beds vary lithologically in different regions, but they are predominantly fine micaceous quartz sands often delicately banded in shades of salmon-pink and yellow. Black, lignitic clays occur in many localities at or near the base. In the southern portion (Salem County) a thick (80–90 feet) bed of chocolate or drab-colored clay occurs, above which there are (or were formerly) exposures of a fine clayey sand containing great numbers of shells (the Shiloh marl of many reports), which, in the localities where it occurs, forms the upper bed of the Kirkwood. The thickness is about 100 feet or more along the outcrop. On the basis of the abundant fauna in the beds at Shiloh, the Kirkwood is believed to correspond in a general way with the Calvert formation of Maryland, the lowest division of the Chesapeake group.

Well-borings at Atlantic City, Wildwood, and other points along the coast have demonstrated the presence there of a great thickness of Miocene strata not apparently represented in outcrop. At Atlantic City clays, sands, and marls from 390 to 1,225 feet below tide carry Miocene fossils, and at Wildwood those from 300 feet to 1,090 feet and perhaps to 1,244 are Miocene. From the fossils it is evident that strata referable to the St. Marys, Choptank, and Calvert horizons of the Chesapeake group are present.

Cohansey sand.—Overlying the Kirkwood at its outcrop is a formation composed chiefly of quartz sand, locally with laminae and

[1] *Report of the State Geologist of New Jersey*, for 1893, p. 346.

lenses of light-colored clay and occasional lenses of gravel. This formation outcrops over a wider area of the coastal plain than any of those heretofore discussed. Obscure casts of molluscan shells have been found in it, but these are of no value in determining its age. Plant remains from near Bridgeton indicate a flora comparable with that of certain European upper Miocene localities. It dips southeastward 9 or 10 feet per mile, and overlies the Kirkwood with seeming unconformity.

Inasmuch as sands and clays similar to the Cohansey are revealed in borings along the coast and there overlie clays carrying Miocene fossils characteristic of the St. Marys, the highest division of the Chesapeake group, the Cohansey apparently belongs to a still later stage of the Miocene or perhaps even to the Pliocene. It is possible, however, that as now defined it may represent in part at least the shoreward phases of the fossiliferous Miocene clays found in the borings along the coast, and that it should be correlated with the Choptank and St. Marys of Maryland. In the light of all data at present available, however, the former view seems most probably the true one.

PLIOCENE SYSTEM

Beacon Hill formation.—Under the term Beacon Hill there were described certain beds of gravel and sand occurring as outliers on the higher hills of Monmouth County. Later the sand beds were correlated with the great body of sand now included in the Cohansey formation, leaving only the gravel in the Beacon Hill formation. It is chiefly quartz, but contains much chert and some hard sandstone and quartzite. The chert pebbles are uniformly much decayed and are frequently very soft. The quartz and quartzites are often more or less corroded. The formation occurs as isolated remnants on some of the highest hills of the coastal plain. It is perhaps to be correlated with the Lafayette formation farther south.

PLEISTOCENE SYSTEM

The Pleistocene formations of New Jersey are glacial and non-glacial, the former occurring in the northern counties, the latter chiefly on the coastal plain. The glacial or glacially derived deposits will first be considered.

GLACIAL DEPOSITS

Kansan or pre-Kansan drift.—Glacial drift, both stratified or unstratified, greatly antedating the moraines of the Wisconsin epoch, occurs more or less discontinuously south of the Wisconsin moraine, to a maximum distance of 23 or 24 miles. In the Highland belt it is thicker and more continuous in the wider valleys than on the ridges, while on the Triassic piedmont plain it caps isolated and more or less flat-topped hills in relations which indicate prolonged erosion, since its deposition. The great age of this drift is indicated by the fact that the main streams have sunk their channels 100 feet and have opened wide valleys on extremely gentle gradients since it was formed. Its complete oxidation and leaching and the disintegration in situ of even large bowlders of gneiss and granite deep within its mass are other evidences of its great age. It is believed to be at least as old as the Kansan drift and may be even older.

Wisconsin drift.—A great terminal moraine of the Wisconsin ice-sheet crosses the state from Perth Amboy to Belvidere. Narrow valley trains of glacial gravels characterize some of the southward drainage lines, notably Delaware Valley, and locally overwash plains are conspicuous topographic features. North of the moraine the rock surface is covered by the usual assemblage of drift deposits, stratified and unstratified. At least two definite halts in the ice retreat are marked by recessional moraines and valley trains which head in them. The warped shorelines of an extinct glacial lake in the upper Passaic Valley indicate a differential elevation of the northern part of the state of about 2 feet per mile, since the retreat of the Wisconsin ice-sheet.

NON-GLACIAL DEPOSITS

The non-glacial Pleistocene deposits consist of gravels, sands, and some clays, chiefly of fluviatile origin, but deposited partly at least in connection with estuarine conditions. Three formations have been differentiated, the Bridgeton, Pensauken, and Cape May, partly on lithologic and partly on topographic grounds. Each of these represents a period in which both erosion and deposition occurred in this region but in which deposition predominated. They were separated by intervals in which on the contrary erosion prevailed over deposition,

although the latter did not cease. Consequently there are, in addition to the deposits referred to these formations, others accumulated during intervals of erosion, whose lithologic, topographic, and age relations are not so clear. Changes of elevation are believed to have accompanied and to some extent to have caused the alternate periods of erosion and deposition, but it is not believed that subsidence was so great as to have depressed all the region in which these beds are now found below sea-level.

Bridgeton formation.—The Bridgeton formation is essentially gravel and sand, the material having been derived from the Beacon Hill, Cohansey, Miocene, Cretaceous, Triassic, Paleozoic, and crystalline formations. Material from the crystallines and Triassic is almost uniformly friable and crumbles readily. Some bowlders are so large and of such a character as to have hardly reached their present position without the aid of floating ice. It occurs as outliers capping high hills, and on divides, and is manifestly now only a remnant of an ancient deposit in large part fluviatile and referable in time of origin to a very early glacial epoch.

The Bridgeton is comparable in a general way to the Sunderland of Maryland, although their limits may not be the same and somewhat diverse views of origin are held by workers in the respective fields. After the deposition of the Bridgeton, there was a long period of erosion during which much of the Bridgeton was removed, particularly in Delaware Valley and along the broad belt of low land stretching across the state from Bordentown and Trenton to Raritan Bay.

Pensauken formation.—The Pensauken formation is chiefly gravel and sand, although locally it contains beds of clay. It frequently much resembles the Bridgeton and cannot always be distinguished from it on lithologic grounds. Where both are present, however, it uniformly occurs at lower levels and has suffered less erosion. It obliterated the smaller and partially filled the larger valleys eroded in post-Bridgeton time, forming broad flood-plain deposits along the drainage lines. The coastal portion of the state was more or less submerged during this period of deposition but the Pensauken formation is conceived to be one due primarily to fluviatile rather than marine or littoral conditions. Since glaciated material

occurs sparingly, it is correlated with a glacial epoch—one, however, which long antedated the Wisconsin drift sheet. In relation to other Pleistocene deposits, it corresponds roughly to the Wicomico of Maryland. Pensauken deposition was followed by a long period of uplift during which the formation was much eroded, nearly all of it being removed from areas favorably situated for erosion.

Cape May formation.—At a later time there was a slight submergence to the extent of 40 or 50 feet below the present stand of the land. During this period terraces were formed at many points along the coast and in valleys which were not submerged. The deposits of this stage constitute the Cape May formation and are believed to correspond in age with those of the last glacial epoch or possibly its later stages. The estuarine terraces along Delaware Bay are continuous with those along Delaware River above Trenton which head in the terminal moraine of the Wisconsin ice-sheet. While along the coast and lower Delaware River the terraces do not exceed 40 feet in height, and are lower than the Pensauken terraces in the same region, yet along the tributary streams they rise to much greater elevations, in some cases equaling that of the Pensauken or Bridgeton.

Since the deposition of the Cape May formation there has been an elevation of the land to something above its present level. Still more recently, subsidence has been in progress and is apparently now going on.

SECTION FOR NEW JERSEY

PLEISTOCENE

GLACIAL		NON-GLACIAL	
Wisconsin Drift	0–250+ feet	Cape May formation	0–20 feet
Unconformity		Unconformity	
Early Glacial Drift	0– 30+ feet	Pensauken formation	0–20+ feet
		Unconformity	
		Bridgeton formation	0–30 feet
		Unconformity	

PLIOCENE ?

Beacon Hill gravel	Variable

MIOCENE ?

Cohansey formation	100–250 feet
(*Sand and clay lenses*)	
Unconformity	

MIOCENE	
Kirkwood formation	100 feet
(*Sand and clay*)	
Unconformity	
EOCENE	
Shark River marl	11 feet
CRETACEOUS	
Manasquan marl	25 feet
Vincentown sand	25–70 feet
Hornerstown marl	30 feet
Tinton bed	10–20 feet
Red Bank sand	0–100 feet
Navesink marl	25–40 feet
Mt. Laurel sand	5–60 feet
Wenonah sand	35–20 feet
Marshalltown clay-marl	30–35 feet
Englishtown sand	20–100 feet
Woodbury clay	50 feet
Merchantville clay	60 feet
Magothy formation	
(*Sand and lignitic clay*)	25–175 feet
Unconformity	
Raritan formation	150–250 feet
(*Sands and variegated clays*)	
Great unconformity	
TRIASSIC	
Brunswick shales	6,000–8,000 feet
Lockatong argillites	3,500 feet
Stockton arkose sandstones	2,300–3,100 feet
Three or more basalt flows and one or more intrusive diabase sills at various horizons. Total maximum thickness	3,000 feet
Great unconformity	

DEVONIAN

UPPER DELAWARE VALLEY		GREEN POND MT. REGION	
		Skunnemunk conglomerate	1,500± feet
		Bellvale sandstone	1,800 feet
Marcellus shale	Traces	Pequanac shale	1,000 feet
Onondaga limestone	Undet.	Kanouse sandstone	215 feet
Esopus grit	375 feet	Not recognized	
Oriskany formation (*Siliceous limestones and sandstones*)	170 feet	" "	

Kingston or Port Ewen shale	80 feet	" "	
Becraft limestone	20 feet	" "	
New Scotland beds (*Cherty limestone and calcareous shale*)	160 feet	" "	
Stormville sandstone	0–10± feet	" "	
Coeymans limestone	40 feet	" "	
	SILURIAN		
Manlius limestone	35 feet	Not recognized	
Rondout limestone	39 feet	" "	
Salina			
Decker Ferry limestone	52 feet	Decker Ferry limestone	
Bossardville limestone	12–100 feet	Not recognized	
Poxino Island shale	Unknown	" "	
High Falls shale	2,300 feet	Longwood shale	200+ feet
Shawangunk conglomerate	1,500 feet	Green Pond conglomerate	1,200–1,500 feet

Unconformity

	ORDOVICIAN	
Martinsburg shale		3,000 feet
Jacksonburg limestone		125–300 feet
Unconformity		
Kittatinny limestone		2,500–3,000 feet
	CAMBRIAN	
Kittatinny limestone		
Hardyston quartzite		5–200 feet
Great unconformity		
	PRE-CAMBRIAN	
Byram and Losee gneiss—rocks of various types, intrusive in older sedimentary rocks		Unknown thickness
Pochuck gneiss, in part intrusive, in part metamorphosed sediments		
Franklin limestone — white crystalline limestone penetrated and surrounded by younger intrusives		Unknown thickness

Reviews

Die Alpen im Eiszeitalter. Von Dr. Albrecht Penck, Professor an der Universität Berlin, und Dr. Eduard Brückner, Professor an der Universität Wien. Gekrönte Preisschrift. Leipzig: Chr. Herm. Tauchnitz, Verleger. In drei Bänden, S. xxxviii + 1200, mit 136 Abbildungen im text, 30 Tafeln, und 19 Karten. Vollständig in 11 Lieferungen à 5 Mark.

This voluminous work, by two of the leading glacialists of Europe, has been seven years in course of publication, the first Lieferung having appeared in December, 1901, and the eleventh or concluding Lieferung in December, 1908. It represents the vacation work of each of these authors for a period of about twenty-five years, and is largely a labor of love, the greater part of it having been carried on independent of official surveys and at private expense.

The plan of the work embraces three volumes, of which the first deals with the glaciations on the north of the eastern Alps, the second on the north of the western Alps, the third in the southern Alps and eastern end of the Alps. The paging, however, is continuous so that the entire work may be bound in a single volume and it has but a single index. The comprehensiveness of the treatment of results of the many studies carried on by various students is shown by the fact that there are 547 different authors either referred to or quoted.

In the first volume, which is entirely the work of Dr. Penck, after a brief setting forth of the problems involved and the methods of study pursued, and a brief outline of leading features in the northern portion of the eastern Alps, attention is first called to the gravel outwash aprons and lines of glacial drainage displayed in the Alpine foreland. The morainic belts are then discussed and then the feeding grounds of the glaciers. Overdeepening is discussed in considerable fulness in relation to the Inn valley system and the rules for overdeepening by glacial erosion are briefly considered.

It was in this field that Penck first worked out the intricacy of the glacial history, and it was done largely through a study of the out-wash phenomena or glacial drainage. It was found that there are four different old fluvioglacial gravel deposits, each of which is connected with a drift sheet. The

gravel deposits are known as the "Aeltere Deckenschotter, Jungere Deckenschotter, Hochterrassen, and Niederterrassen," while the corresponding drift sheets are named "Gunz, Mindel, Riss, and Würm," the names being taken from type localities in the Alpine foreland. The relative ages of the deposits of each glaciation are determined by a study of the relative amounts of geologic work accomplished by erosion, sedimentation, and weathering since their deposition. The first two glaciations are found to be much more remote than the last two, and form what are called the older group, while the Riss and Würm form the younger group, yet the alteration of the Riss is sufficient to indicate that it is more than twice as old as the Würm. The classification here made was found to hold good throughout the entire Alpine field, and as a result of the wider study the relative ages of the several glaciations, as summed up in the concluding Lieferung, place the Riss three times as far back as the Würm, and the Mindel at least twelve times as far back as the Würm, while the Gunz is considered about one and one-half times as old as the Mindel, the data for estimating its age being rather imperfect. In this first volume Penck brings out clearly the minor oscillations shown in the last or Würm glaciation. To each readvance made by the ice he applies the term stadium and recognizes three that lie between the maximum limits of the Würm glaciation and the limits of the present glaciation, namely the Bühlstadium, Gschnitzstadium, and Daunstadium. These stadia are found to be capable of differentiation in many other parts of the Alps. This first volume also discusses briefly the interglacial deposits and the difficulties of their interpretation. It is the custom of these authors to class deposits as interstadial rather than interglacial except in places where the evidence is very clear that they were laid down in a much warmer climate than would be consistent with a glacial stage. Where, for instance, warm-climate plants are found to be imbedded in the deposit, as in the Hötting breccia near Innsbruck, the deposits are referred confidently to an interglacial time.

While the first volume is entirely from the pen of Penck, it should be stated in justice to the work done by Brückner, that the results of his studies in the Salzach district, which appeared in 1886 in the form of a monograph are here abstracted by Penck.

In the second volume which deals with the glaciation north of the western Alps, Brückner discusses the glaciers of Switzerland, while Penck discusses the Rhein glacier and the portion of the Rhone glacier in France and the Isère glacier. Penck also discusses the Quaternary fauna and Paleolithic man in the Rhodanischen district and on the north side of the Alps. The four glacial stages brought out in the first volume are clearly

represented in the district covered by the second volume, but there is an interesting difference in the relative extent of the Riss and the Mindel glaciations in the two districts. In the eastern district the moraines of the Mindel glaciation generally extend beyond the limits of the Riss, but in the western district the Riss usually marked a greater extent of glaciation. Brückner has suggested elsewhere that a considerable part of the Quaternary uplift in the western Alps may have fallen in the Mindel-Riss interglacial time, and that this, rather than a greater depression of the snow line, accounts for the great extension of the Riss glaciation in that region. In the present discussion, however, the question is left open as to whether the Riss or the Mindel experienced the greatest depression of the snow line. Both glaciations were more extensive than the Würm and also than the Gunz. This western region is exceptionally favorable for studying the relations of the Quaternary fauna to glaciation, and also Paleolithic man in his geologic relations. The transformation of the fauna of the glacial period is found to correspond closely to the change from glacial to interglacial conditions. On the north side of the Alps there appears an Arcto-Alpine fauna characterized by the mammoth, wooly rhinoceros, and reindeer, and an interglacial fauna characterized by the ancient elephant, *Rhinoceros Mercki*, and the deer. In Switzerland there is a sharp line separating the two Arcto-Alpine faunas from an intermediate interglacial fauna, though there are occasional occurrences of a mixing of the two faunas, for example of the deer and the reindeer. The geographic extension of the localities in which each of the Arcto-Alpine faunas occurs furnishes a basis for correlating their occurrences with stages of the glacial period. The older fauna comes up about to the limits of the Riss glaciation, while the younger fauna extends to the limits of the Würm, in fact it extends about to the limits of the Bühlstadium, and thus shows its somewhat close correspondence with the Würm glaciation.

The stage of human culture apparently prevalent at the time of the Riss-Würm interglacial period is that designated the Moustérien. By the close of the Würm glaciation the culture had advanced through the Solutréen to the Magdalénien. What is regarded by Penck as the most impressive case of the occurrence of a Moustérien type of artifacts with an interglacial fauna came to notice subsequent to the publication of this volume, but is discussed by him in the eleventh or concluding Lieferung. It is known as the Wildkirchli locality and is found in the Ebenalp of the Santis, east of the upper Rhein and south of Wallen See. Explorations by Emil Bächler, of a cave which stood above the limits of glaciation in that region, at an altitude of about fifteen hundred meters, shows the presence of hundreds

of stone artifacts, of the Moustérien type, imbedded with an interglacial fauna represented by the cave bear, cave lion, *Cervus Elaphus*, etc., in about five meters of cave earth, which is covered by rubble to a depth of 0.8 meter.

Penck holds that the cave earth calls for a thick vegetation in the district above the cave, and that the presence of these animals also strongly suggests such vegetation. He concludes that when these bones and artifacts were imbedded this region was warmer than now, for the cave is near the present timber line. There is no evidence that the fauna, whose remains are here imbedded, has occupied the region since the last or Würm stage of glaciation. This fact, taken with the stage of culture shown in the artifacts, gives a strong presumption of, if it does not clearly prove, man's presence there prior to the Würm stage of glaciation. Other instances, which have been cited to indicate man's presence prior to the last glaciation, such as those in the French Jura at Conliége, and Hautecour, are in Penck's opinion less clearly interpreted than the Wildkirchli.

In the third volume the Durance and several small glaciers on the west side of the southern Alps, as well as the glaciers on the east side of these Alps, are treated by Penck. Those on the south side of the Alps in northern Italy, are discussed in part by Brückner. Of those in the eastern Alps the Save glacier is discussed by Brückner, while the Drau and those of the Mur district are discussed by Penck. The conclusion (Schluss) which contains a résumé of the physiographic and climatic conditions, and the chronology of the glacial period, is by Penck.

The moraines formed on the borders of the Po plain in northern Italy reach enormous proportions, one on the edge of the Dora Baltea glacier attaining a height of about 500 meters above the low plain which it incloses, while those on the borders of Lago di Garda reach a still greater height above the bed of the lake. It is shown by Penck that the great Dora Baltea moraine, as well as those of several other glaciers, were formed mainly prior to the last or Würm glaciation. This was also the case on the north side of the Alps, but it has not been so clearly worked out in that region, though the outwash in the earlier stages points to more vigorous glaciation than obtained at the Würm stage of glaciation.

In the conclusion, which covers 36 pages, several points are more clearly presented than in the somewhat diffuse detailed discussion. Among these are: (1) The snow line of the several glacial stages in comparison with that of today; (2) the causes for the depression of the snow line; (3) difference between snow line and timber line in the ice age; (4) position of the snow line on the glacier surface, and the conditions of the zone of waste and zone

of accumulation; (5) the rapidity of Alpine glacier movement in the ice age; (6) aspect of the different parts of the Alps in the ice age; (7) character of the fauna and flora on the north side of the Alps; (8) the loess; (9) the climate curve of the glacial period; (10) absolute length of postglacial time and of the entire glacial period.

We cannot enter into a review of each of these subjects but will speak only of the loess, and of the estimate of the absolute length of the glacial period. Typical fossiliferous loess is rather rare in the entire circumference of the Alps. Usually the deposit to which this term has been applied is a loam having some loess characteristics. This loam is best developed north of the Alps and is present on each of the older drift sheets, but not on the younger or Würm drift. Where there is an overlap of drift sheets it is found between them, in the position of an interglacial deposit. But while interglacial in position its fauna is not entirely of an interglacial type of warm climate animals. The mammalian remains in it are usually of the Arcto-Alpine type. Penck makes the suggestion that the loess was deposited in advance of a stage of glaciation in a sort of tundra condition with scanty vegetation. That the loess of the Riss-Würm interval closely preceded the Würm glaciation is indicated by the character of artifacts found at its base. They are closely allied to those which followed the Würm glaciation. The solution of the loess problem it is thought may be worked out more satisfactorily in the broad loess-covered areas of eastern Europe than in the rather limited area on the borders of the Alps.

As to the absolute duration of post-Würm time and of the entire glacial period, Penck attempts only to present data that will serve to indicate roughly its order of size. From Heim's estimate on the rate of growth of the Muota delta and similar estimates elsewhere in the Alps it appears that the Bühlstadium of the Würm stage of glaciation was reached between 16,000 and 24,000 years ago. It is safe to conclude, therefore, that the culmination of the Würm glaciation was somewhat more than 20,000 years ago. This estimate is borne out by a study of the Swiss lake dwellings in their geologic relations. They are more recent than the Daunstadium, and yet lie back at least 4,000 to 4,500 years. Inasmuch as the changes effected by geological agencies on the drift of the Riss glaciation are fully three times the amount effected in the drift of the Würm stage and the changes in the Mindel drift twelve times that in the Würm, the Riss glaciation would have culminated fully 60,000 and the Mindel 240,000 years ago.

The illustrations which accompany the work embrace many excellent photographs and several good maps as well as numerous diagrams. Among the maps that of the Etsch glacier and the moraine amphitheater of Lago

di Garda, and the map of the Drau glacier and its neighbors, are the most complete, since they indicate the upper limits of glaciation by means of isohypsal lines. The data for such maps involve a vast amount of work such as it was not possible to extend over the entire Alpine field. As a rule each determination of the upper limits of glaciation required an all-day climb. Penck once remarked, in the presence of the reviewer, that his ascents and descents of mountains in the Alps involve a distance sufficient to reach from the Alps to the South Pole, or from the Alps to the North Pole and back again. One who has not attempted Alpine work can scarcely appreciate the great labor involved in carrying out such a study as that accomplished by Penck and Brückner. The only serious defect noted in this publication is the absence of a general map of the entire Alpine region, though this is offset to some extent by the adoption of a uniform scale (1:700,000) for the several maps of the sections of the Alps. It is also to be borne in mind that even at the culmination of glaciation the Alpine region did not support a continental ice mass. The glaciers which became united on the Alpine foreland were of the Piedmont type, and many glaciers remained entirely independent throughout their course.

Die Alpen im Eiszeitalter, although an expensive publication, the cost of the eleven parts being 55 Marks, or about $13.00, cannot well be left out of the library of any active geologist, and should be included in every university library. By those who have not a command of the German language a large amount of information may be obtained from the excellent maps, views, and diagrams.

FRANK LEVERETT

The Life of a Fossil Hunter. By CHARLES H. STERNBERG. Introduction by HENRY FAIRFIELD OSBORN. New York: Henry Holt & Co.

The author of this interesting personal narrative is one of the oldest vertebrate fossil collectors in America. Mr. Sternberg made his first expedition in the Kansas chalk for Professor Cope during the summer of 1876. Specimens collected by him from many of the vertebrate-bearing horizons of the western United States are to be found in many of the museums of America and Europe. Beginning his work at a time when America had but three vertebrate paleontologists, Mr. Sternberg has seen the science advance until now there are over forty specialists engaged in it and to this advancement he has contributed not a little by his industry and skill as a collector. He has persevered in his chosen work in spite of hardships and financial difficulties. His wide acquaintance with paleon-

tologists throws side-lights on the personnel of the profession and especially interesting is his characterization of Cope with whom he was associated for years.

A few errors of a minor character which subtract little from the general readability of the book should be mentioned. Mr. Sternberg's first expedition to the Kansas chalk was in 1875, not in 1876. The restoration of Triceratops, opposite p. 270, is obsolete, as is that of Elasmosaurus, opposite p. 123, and they should not have been used. Lysorophus, mentioned on p. 258, as a lizard and a connecting link between amphibians and reptiles, has lately been shown by Professor Williston to be a Urodele and a much more highly specialized form. The author's zeal has sometimes led him into the mistake of unduly magnifying the importance of museums containing his own collections to the derogation of certain others, as for instance the statement on p. 112, accredited to Professor Osborn, that the Munich Museum contains the finest collection existing of specimens from the Kansas chalk, whereas as a matter of fact the collections from this horizon in the museums of Yale University and the University of Kansas far exceed in importance those of any other.

C. L. B.

Geological Survey of Ohio. By J. A. Bownocker, State Geologist, N. W. Lord, and E. E. Somermeier. Fourth Series. Bulletin No. 9, 1908. Coal. 342 pp., 7 pls., 2 maps. Columbus, 1908.

This report is the first under the supervision of the present state geologist. It deals entirely with the coals. Part I treats those of the Monongahela formation or the Upper Productive Measures, and Part II deals with the four seams of the Allegheny formation or the Lower Productive Measures. One hundred and fifty-one sections are given with descriptions, analyses, and calorific values. Chap. viii is an interpretation of the chemical and physical tests. Chap. ix is a description of the methods used in the analyses.

C. J. H.

32nd Annual Report of the Department of Geology and Natural Resources of Indiana. By W. S. Blatchley, State Geologist. 1158 pp., 79 pls., maps. Indianapolis, 1908.

The various reports of the soil survey are given in the first part of the work. The early report of Hopkins and Siebenthal on the Indiana Oölitic limestone is revised to keep pace with the growing industry which in 1907 amounted to three and one-half millions. The production of petroleum has declined, due to the migration of operators to other states. The report of

the inspector of mines is largely statistical. The supervisor of natural gas outlines improvements for the abuses now allowing unnecessary waste of a valuable resource. The major portion of the volume is upon the stratigraphy and paleontology of the Cincinnati series. The smaller alternation of shale with limestone in the Cincinnati beds is attributed to climatic conditions while the sudden change of fauna and type of sediment is attributed to epeirogenic causes. The Richmond of Indiana is considered the time equivalent of the Medina of New York. A complete résumé of the fossils described from the series is given. C. J. H.

Wisconsin Geological and Natural History Survey. E. A. BIRGE, Director, and L. S. SMITH. Bulletin No. XX. Economic Series, No. 13. Water Powers. 354 pp., 52 pls. Madison, 1908.

After a brief description of the physical geography of the state, the author divides the work into two parts: the first dealing specifically with the water-power resources of northern Wisconsin, and the second with those of southern Wisconsin. C. J. H.

Waste of Our Fuel Resources. Address of DR. I. C. WHITE, State Geologist of West Virginia, at the Conference on the Conservation of Natural Resources, held at the White House on the afternoon of May 13, 1908.

The extent of the large deposits of coal, petroleum, oil, and gas is briefly stated. The wanton waste of them is characterized in a forceful manner. Our industrial rivals—France, Germany, and Great Britain—have no supply of the purest of fuels, natural gas, of which there are wasted in the United States 1,000,000,000 cubic feet daily, the equivalent of 1,000,000 bushels of coal. For every barrel of oil taken from the earth ten times its amount has been lost one-half of which may be saved. From 40 per cent. to 70 per cent. of the coal is irretrievably lost in mining.

C. J. H.

Oklahoma Geological Survey. BY CHAS. N. GOULD, Director, L. L. HUTCHISON and GAYLORD NELSON. Preliminary Report on the Mineral Resources of Oklahoma. Bulletin No. 1, 1908. 88 pp., 11 figs. Norman, 1908.

This bulletin is the first report of the recently formed state geological survey. Its purpose is to direct attention to the vast resources, to foster

home industries, and to discourage useless prospecting. The enormous deposits of coal, gypsum, asphalt, salt, oil, gas, shale, limestone, and clay are described, and their approximate locations given. Lead, zinc, granite, gabbro, porphyry, marble, tripoli, novaculite, and volcanic ash are important deposits. Iron and copper are too widely disseminated in the rocks to be of value. Gold and silver are not likely to be found. The gypsum and asphalt deposits are among the largest in the United States. The granite and porphyry are of the finest quality. The introduction of better means of transportation will stimulate the mineral industry of Oklahoma.

C. J. H.

Some Problems of the Formation of Coal. By David White. Reprinted from *Economic Journal*, Vol. III, No. 4, 1908.

The author states that typical coal plants grew in greatest profusion under a humid and equable, though not necessarily tropical, climate. The size and state of preservation of delicate plants is affirmative evidence of accumulation in regions of growth. Transported plant remains are characterized by their macerated condition.

Anaerobic bacteria are primarily indispensable as an agency in the decomposition of organic matter, forming algal, fundamental matter, or sapropel. The process which is essentially bio-chemical probably leads no further than the formation of peats, humus, sapropelic deposits, etc. In the dynamo-chemical stage of coalification the anthracites, bituminous coals, and lignites are metamorphosed from peats, lignites, etc. Devolatilization, the writer believes, is caused not by folding or faulting, but by deep-seated horizontal thrust movements. Lithification and partial dehydration are attributed to loading pressure: De-oxygenation and de-hydrogenation which are essentially chemical results are due rather to bio-chemical changes than to dynamic stress.

In a future paper the writer hopes to show clearly that de-oxygenation is a true index of the progress made in the formation of coal and its efficiency as a fuel.

C. J. H.

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JULY-AUGUST, 1909

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THE
JOURNAL OF GEOLOGY
JULY–AUGUST, 1909

THE FAUNAL RELATIONS OF THE EARLY VERTEBRATES

S. W. WILLISTON
The University of Chicago

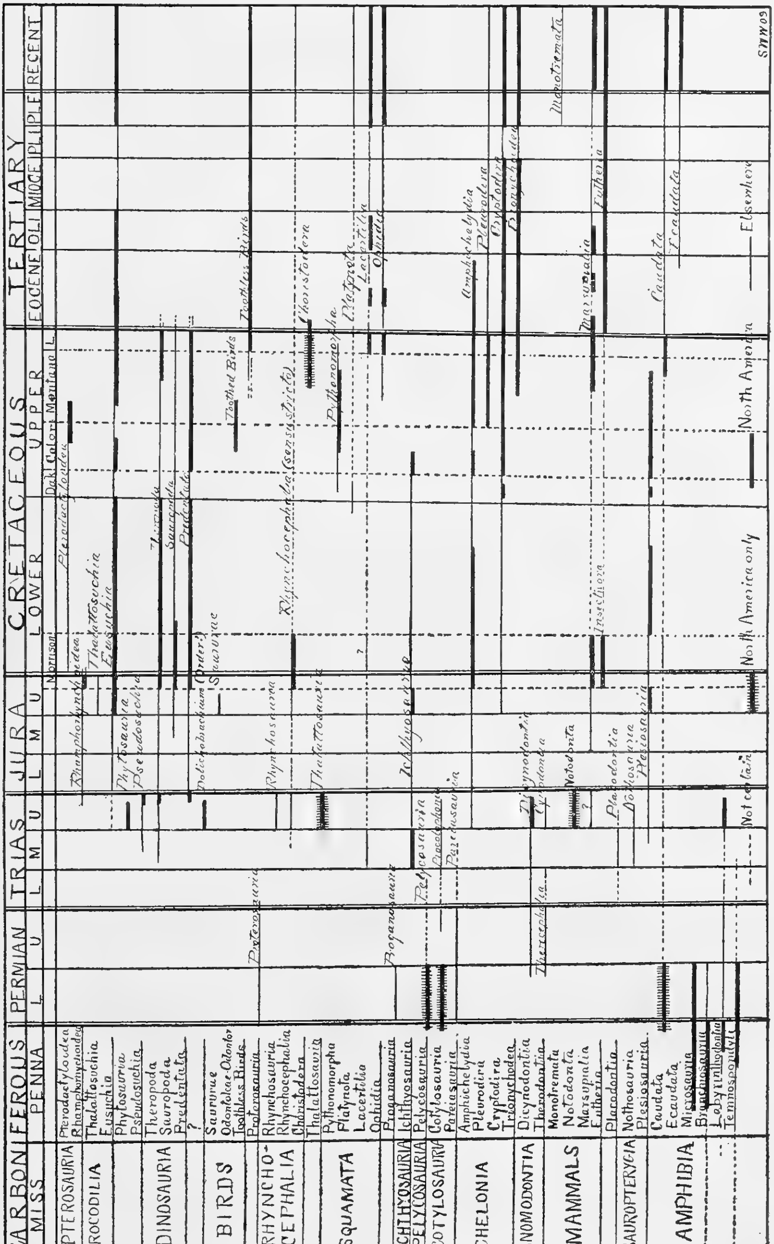
VIII

The environmental conditions affecting the evolution of the early air-breathing vertebrates offer at the present time many peculiarly difficult problems, problems which must depend in large measure upon the geologist for solution. They are very different from those which confront the student of the neozoic vertebrates, since we have better data for comparisons and conclusions in the living faunas as well as in our existing climatic and geographic conditions. And especially are the problems more involved and complicated when we attempt to deal with the marine or aquatic air-breathers of those early times. Here we can practically predicate little as to the conditions of the oceans and climates in which they lived. But these early vertebrates do offer, it seems to me, much that is suggestive regarding the migrations and evolution of faunas, involving theories as to paleogeographic conditions and changes, and, within certain limits, the climatic conditions which surrounded and controlled the migrations. And it is of this phase of the subject that I would choose to speak now.

As has been said, the evidence offered by the vertebrates, when available, is often, if not usually, more decisive than that of any other class of organisms in the determination of the relationships and correlations of faunas. A single species of the higher vertebrates

found to occupy two remote provinces would furnish more positive evidence of contemporaneity and the possibilities of faunal migrations than would scores of others of lower types. But of species in vertebrate paleontology we can say little; the term with us is usually a far more vague and indefinite one than it is among students of living faunas, partly because much of the evidence which the neozoölogist has, the paleozoölogist has not, partly because the taxonomy of living creatures is still based too much upon superficial resemblances. And really, for most purposes, genera express in vertebrate paleontology about what species suggest among invertebrates and plants, that is for correlative and evolutional purposes, at least.

The evolution of vertebrate life, air-breathing vertebrate life, for I shall not presume to speak of the fishes, during Carboniferous times was quite as great as at any subsequent period. Indeed, I think I am quite safe in saying that, so far as the chief problems in vertebrate evolution are concerned, the life of the Carboniferous is the most important of all. From forms scarcely differing from fishes which must have existed at the beginning, of which, alas, we yet have no knowledge, we find evolved at the close forms foreshadowing the chief groups of life of modern times. The predominant types of the Pennsylvanian were what we usually call the branchiosaurs and microsaurs, for the most part small or very small creatures, at least as small as their nearest relatives of the present time, the salamanders. We are quite justified in the belief that their habits in general were not greatly unlike these descendants, rather sluggish creatures living about or in the water, for the branchiosaurs at least passed through larval stages. They were more or less protected by an external bodily armor against their enemies, whether of their own or other kinds, in all probability terminating their existence as distinctive types long before the close of the Paleozoic. But among them there were some classed with the heterogeneous group which we call microsaurs, which had made a very distinct advance, both toward a higher existence and away from the water. It has been assumed on entirely insufficient evidence that they too were all amphibians, having an early larval existence in the water, but of this we have, for many of them, little or no proof, and there is very little to differentiate the most advanced of them in structure from the reptiles. Some lost the


CARBONIFEROUS
MISS
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JURA
CRETACEOUS
LOWER
UPPER
TERTIARY
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PLI
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RECENT
Morrison
Dakota
Colorado
Montana
L.
PTEROSAURIA
Pterodactyloidea
Rhamphorhynchoidea
CROCODILIA
Thalattosuchia
Eusuchia
Phytosauria
Pseudosuchia
DINOSAURIA
Theropoda
Sauropoda
Predentata
BIRDS
Saururae
Toothless Birds
Toothed Birds
RHYNCHO-CEPHALIA
Proterosauria
Rhynchosauria
Rhynchocephalia
Choristodera
Thalattosauria
SQUAMATA
Pythonomorpha
Platynota
Lacertilia
Ophidia
Proganosauria
ICHTHYOSAURIA
Ichthyosauria
PELYCOSAURIA
Pelycosauria
COTYLOSAURIA
Cotylosauria
Pareiasauria
CHELONIA
Amphichelydia
Pleurodira
Cryptodira
Trionychoidea
ANOMODONTIA
Dicynodontia
Therodontia
MAMMALS
Monotremata
Marsupialia
Eutheria
Insectivora
PLACODONTIA
Placodontia
SAUROPTERYGIA
Nothosauria
Plesiosauria
AMPHIBIA
Caudata
Ecaudata
Microsauria
Branchiosauria
Labyrinthodontia
Temnospondyli
North America only
Not certain
North America
Elsewhere

dermal armor completely and became fleet of movement, as is evidenced by the structure of their limbs, limbs mimicking in form and in structure so closely those of modern quick-running lizards as to be practically indistinguishable. We may be assured that some of them before the close of the Pennsylvanian were inhabitants of high-and-dry land regions where fleetness of movement, rather than obscurity, preserved them from their enemies, crawling reptiles in everything save some insignificant technical details of their palates. Specialization of the microsaurs had reached the extraordinary extent of snake-like limbless forms.

In addition to these two types of land animals we have two others which either persisted from unknown ancestors or made their advent: the temnospondylous type of amphibians from which the mammals eventually arose, and the stereospondylous type which terminated in the gigantic labyrinthodonts of the Upper Trias, the only group of the Pennsylvanian air-breathing vertebrates which we may say with certainty has left no modern descendants behind them. However, till near the close of the Pennsylvanian we have no knowledge of anything distinctive in the American land-vertebrate fauna. There was nothing strikingly peculiar to either eastern or western continent, so far as our knowledge yet extends, and some of the forms, indeed, are almost if not quite identical generically. And the only possible explanation of this homogeneity of types is freedom of communication and migration, the persistence and wide extent of like climatic and freshwater conditions that would permit, for instance, the migration of snake-like forms of small size from Ohio to Ireland and Bohemia without material modification in structure.

However, either the divisional lines between the Pennsylvanian and the Permian have been placed too high, or else, it seems to me, evolution among the vertebrates was more rapid in America than elsewhere near the close of the period. As a continent I believe that the land of America was absolutely and continuously isolated, so far as the intermigrations of land forms was concerned, from some time before the close of the Pennsylvanian till well into Triassic times, as they reckon them in Europe. Of the Permian vertebrates by far the richest and most varied fauna known is that of America, and especially that of Texas and Oklahoma. Professor Case has recently presented

what evidence he could for the Permian age of this fauna and has admittedly failed in proving anything save its utter isolation, and from the evidence we yet have no one can do better than he has done. The fauna was literally *sui generis* and I may almost say *sui ordinis*. But two or three genera of two types out of the scores of genera known from these regions can be correlated as showing resemblances—family resemblances I mean—with foreign forms. And both of these types had made their appearance, admittedly now here in America, before the close of the Pennsylvanian, one the derivative of Upper Carboniferous, possibly sub-Carboniferous stock, the other a later development, and both continuing for a brief period in Europe during Permian times. Of all the remainder of the air-breathers not one can be compared with forms known elsewhere in the world, save in the general characters, ordinal characters at best.

These facts can mean but one thing, the faunal isolation of land and freshwater vertebrates during all of the so-called Permian times in America. The faunistic evolution here was great, however. At least three very distinct phyla of reptiles and as many of amphibia are known with certainty: the Pelycosaurs (Naosaurus, Dimetrodon, etc.), derivatives of a prior type which had branched off before the close of the Pennsylvanian; the true Cotylosaurs (Otocoelus, Diadectes, etc.) with, in some cases, singular developments of dermal carapace, strongly suggestive of the turtles, unknown elsewhere; and a third type (Labidosaurus, Pariotichus, etc.), for the present nameless, small crawling reptiles with large head, short tail, short limbs, whose nearest, but remote relatives are found among the pareiasaurs of South Africa, doubtless derived from the same common stock as the pareiasaurs, but modified by long isolation. Of the amphibia the most numerous and best developed are those with temnospondylous vertebrae, that is those which have the vertebrae divided into separate elements, the type from which the mammals doubtless eventually arose, as well as the cotylosaurs, and pareiasaurs. This group is also abundantly represented in the Lower Permian of Europe, but reached the highest expression in the Texas Permian (Eryops) A second type, represented by a few forms, in America, known from the latter part of the Pennsylvanian throughout the Permian (Diplocaulus, Crossotelos, etc.) represents sparsely the continuation of the microsaurs

perhaps, but with marked modifications in structure peculiar to the American forms which separate them widely from their Permian relatives of Europe. The third, representing the earliest known type of the modern amphibians (Lysorophus), is, so far, entirely peculiar to our Permian, another evidence of isolated evolution. There are no known representatives of the stereospondylous types of Stegocephalia, that is the true labyrinthodonts, which, however, as we shall see, suddenly reappear in the Upper Trias, and doubtless were represented in the later Pennsylvanian of this country by known forms from Kansas, and by Marsh's Eosaurus from Nova Scotia, etc. Upon the whole, then, our Permian fauna is sharply and almost completely distinguished from any supposed contemporaneous or indeed any fauna known elsewhere, and may have been evolved wholly in America from known Pennsylvanian forebears. The Texas and Oklahoma Permian deposits were undoubtedly for the most part or entirely those derived from extensive flats of slight elevation, deposits composed for the most part of the finest, almost impalpable mud, with little extraneous material, traversed here and there by current channels, and streams which have left for evidence interrupted ribbons of fine or coarse sandstone, and some beds of gravel, with intercalations everywhere of lenticular masses of very fine sandstone of aeolian or quiet water origin. In other words, as has often been said, the deposits are typical shallow freshwater deposits, gradually merging on the north, as Beede has recently shown, into the shallow marine deposits of the Lower Kansas Permian. Few if any real marine vertebrates are known from all these extensive and varied deposits, since the shark and dipnoan remains not infrequently found may have been, and doubtless were, of fishes already habituated to fresh or brackish water. That there may have been in America contemporaneous forms living on the higher lands of which we have yet no knowledge is doubtless true, but not very probable; the higher grounds of the Wichita Mountains on the north have sent abundant gravel and sand material southward into these deposits, and they surely would also have sent some fragments of distinctive high-land creatures with them had there been any. There is, I believe, in all these deposits, not a single hint of the ancestry of modern reptiles save possibly of the turtles and ichthyosaurs. Nor do I believe that there is any evi-

dence of the great phyla of archosaurian and synaptosaurian reptiles here, for I, for one, am pretty thoroughly convinced that the Pelycosaurs have no genetic relationship with either of these groups. The origin of the branch leading to the mammals, so far as our knowledge yet goes, was in Africa; there is nothing to prove that it was in North America. What then became of the Permian land fauna of North America? Not a trace of it is found later in the Mesozoic land fauna of America. Until we know more of the land fauna of South America, during these and later times, it is impossible to say just what became of it, but certainly, with the close of the Permian time, so far as our knowledge yet goes, it was completely blotted out of our records.

How much longer this Permian isolation continued it is of course impossible yet to say, since the gap in our records to the Upper Triassic is complete and absolute, at least so far as distinctively land forms are concerned. Dr. Merriam has brought to light within recent years from the Pacific regions a comparatively rich and varied marine vertebrate fauna of the Middle and Upper Trias, but it does not throw much light on continental faunal conditions. The remarkable demonstration of evolutional characters presented by the numerous ichthyosaurs which he has discovered indicates, it seems to me, a dispersal center of these animals, a group which must have been derived from the most primitive of reptiles, such indeed as the Permian fauna of America presents; and they may have been the direct descendants of that fauna. With them, moreover, is associated a remarkable new group of reptiles, the thalattosaurs, of almost subterrestrial type, unknown elsewhere in the world, a form which may have arisen from Lower Triassic land reptiles of true rhynchocephalian affinities, the first indication of this type, I believe, in America. Where their ancestors came from we cannot say, but I believe that they were immigrants, since we know of nothing that could have been their progenitors from the Permian of America.

With the land fauna of the Upper Trias of America we have again the most astonishing proofs of an intermingling of European and American faunas, an opening-up of some broad land connection which had been interrupted during Permian times. In the phytosaurs and the nearly contemporaneous thalattosaurs of the Pacific Triassic we have the first definite indication of the great archosaurian group

of reptiles, already represented since early Permian times in Europe. Both they and the associated labyrinthodonts, which had been wholly absent since Carboniferous times, show the most intimate affinities with the European types, proving beyond doubt the equivalency of the deposits yielding them with the Keuper of Europe. And, also associated with them, are true dicynodonts—of this I have no doubt—forms intimately allied to those of similar age in the Trias of South Africa, the first representatives in America of another great group of reptiles, the Synaptosauria. Between the horizons yielding Permian fossils, whether vertebrate or invertebrate, and that affording these Keuper Triassic animals, there are, in both Kansas and the Lander region of Wyoming, at least a thousand feet of continuous, conformable, uninterrupted, and homogeneous deposits of red sandstones, deposits utterly barren of all animal or plant remains. I have asked geologists in vain what such deposits mean. One thing they do mean, for the Rocky Mountain region at least—continuous and uniform physical conditions. What became of the Permian vertebrates during this interval we cannot say, for, as I have said, there is, I believe, not the slightest trace of them or their descendants in the land fauna. And from the east, as also from the west, we get before the close abundant evidence of dinosaurs and aetosaurs; and a peculiar type of mammals, from Carolina.

Again comes a most lamentable gap in our knowledge of land vertebrates in America, that of the Lower and Middle Jurassic. With the Upper Jurassic marine beds, come in the most specialized of the ichthyosaurs and highly specialized plesiosaurs and a single fragmentary specimen of a crocodile, the first from the American continent. Both the ichthyosaurs and the plesiosaurs show such high evolution that we must admit their recent migration from Europe, where indeed a closely related ichthyosaur had anticipated our form and the plesiosaurs had long been known.

With the close of the Jura a rich land fauna appears in the Morrison beds, rich but not varied, composed almost exclusively of dinosaurs, dinosaurs big, dinosaurs small, carnivorous, herbivorous, walking, running, almost flying dinosaurs, of high and low degree, but among them all not a single type that is distinctively American, not one that is not, prior to this time or as a contemporary with it, known

from the eastern continent. Morosaurus mimics Cetiosaurus, Camptosaurus Iguanodon, Stegosaurus Omosaurus, Allosaurus Megalosaurus, etc. We are confident then that during Morrison times there was freedom of migration between the eastern and western continents, so free that nothing distinctive of our fauna had been developed through isolation. Here now we find for the first time meager representatives of the first turtles, of a single type, which had been known on the eastern continent since Middle Triassic times, almost the first crocodiles, well known also there since Triassic times, but represented here by a single form with relatively few individuals, of a distinctively European genus. Nothing else save a single fragmentary bone of what may have been a pterodactyl, and a recently discovered (Gilmore) terrestrial rhynchocephalian, known over there from the Permian, Trias, and Jurassic; not a nothosaur, so characteristic of the European Triassic land fauna, not a lizard, known from the Triassic of Africa, not a bird, known from the Upper Jura of Solenhofen, practically nothing but dinosaurs, and mammals very closely allied to the Kimeridge or Wealden mammals of Europe—the first known multituberculates here, but known from the oölite there. Can one conceive of more favorable conditions for the preservation of the remains of all these creatures and of the small salamanders known contemporaneously in Europe, than those which existed through the thousands of miles of extent of low-lying, marshy lands of Morrison times? It will not suffice to say that we may yet find them in America. Under far less favorable conditions, apparently, bird remains are found in the Upper Cretaceous of New Jersey, Kansas, and Wyoming.

The conditions and faunas of the Morrison times are continuous throughout the Lower Cretaceous, so far as we know them; nothing new, nothing different save the reappearance of the plesiosaurs, nothing strange, nothing distinctive, and no type missing.

With the Upper Cretaceous the meager fauna of the Dakota gives only the footprints of a bird and a more distinctively terrestrial turtle. In the Benton, aside from the marine plesiosaurs, which here reach their culmination perhaps, and the ichthyosaurs, which now are dying out here after their disappearance in Europe, we find the last of the broad-nosed crocodiles (Coelosuchus) of ancient type, another

lingerer, which had apparently disappeared in Europe, and the first of the slender-nosed crocodiles of olden type, their first appearance here after their last records from the eastern continent. And with them appears for the first time a new type of dinosaurs, the armored polacanthids (Stegopelta) which had appeared in Europe in the Wealden, but which is unknown from the earlier deposits of America among all the vast numbers of dinosaurs. With the close of the Benton and the beginning of the Niobrara, we find the first appearance of distinctive American types of air-breathing vertebrates since the decay of the Permian fauna, save the thalattosaurs of the Pacific Trias, in the large marine turtles (Protostega) and the duck-billed dinosaurs (Claosaurus). And what is very interesting is the first appearance of the scaled reptiles, the mosasaurs, in America. But the mosasaurs had already reached a high degree of importance in the east and perhaps in the south. They appear here suddenly without any such premonitions as are found in southern Europe, long after their appearance there. Although marine animals, they live near the shores and doubtfully ever braved the oceans; they must have followed the land. The birds, too, now are numerous and of considerable diversity of form; and the pterodactyls swarmed the seas, pterodactyls which had gradually been evolving in Europe till they had reached almost or quite the American specialization in the Cambridge Greensand. What was the cause of their delay in reaching this continent? Certainly not our lack of knowledge of the faunas, for I believe that we can say with tolerable certainty that no pterodactyls were in existence here till the time of the Colorado Cretaceous, certainly none of the Cretaceous type which began in the Wealden of Europe. The plesiosaurs, on the other hand, have taken on specializations which, notwithstanding their supposed freedom of migration, indicate comparative isolation from the European forms, for not a single genus is identical, and, save possibly Platecarpus, there is not a single genus of mosasaur quite identical with those of the European fauna. Unfortunately we know little of the land animals of this epoch, but altogether I think we are justified in saying that the freedom of communication between European and American land vertebrates was somewhat restricted.

During the times of the Fort Pierre and Laramie, inclusive of the

New Jersey and Judith River faunas, we get some notable, though very dilatory appearances of European forms, the first land scaled reptiles, the first salamanders, and, with them, the first of the modern type of crocodiles, allied to the Borneo gavials. And with them also, the very much belated long-headed crocodiles of ancient type gave up the ghost, while the duck-billed and horned dinosaurs and the marine turtles, all distinctively American forms, the most distinctive of American Mesozoic vertebrates save thalattosaurs that we have, waxed and grew mighty. A new type for America of terrestrial turtles appeared. The polacanthid dinosaurs, long since unknown in Europe, continued to the very close (Paleoscincus). The mosasaurs present a European genus (Mosasaurus), but one that was most certainly developed here in America, and emigrated. Finally at the close a new type of reptiles (Choristodera), with marked rhynchocephalian affinities, appears both here and in Europe, continuing on into the Tertiary, in forms almost generically identical; and the same may be said of the American crocodiles (Thoracosaurus) which reappear in Europe in the early Tertiary, with scarcely any differences.

And all these facts indicate conclusively a continued intermigration between the eastern and western continents of land animals, with possibly some less freedom during late Cretaceous times.

To summarize: The Pennsylvanian fauna has nothing distinctive, at least till near the close; there must have been a continuous and free interchange of land animals with the eastern continent till near the close. Before its close, it had already diverged and certain true reptiles had appeared. Before the beginning of Permian times an interruption of migration occurred, producing a complete and continuous isolation of the Permian American fauna. With the close of these times a long interval elapsed, during which physical conditions were almost uniform over a large part of the Rocky Mountain area at least; during which interval we have no records of land or freshwater life, but which is represented in part by marine forms of remarkable character, possibly in part derived from American ancestors. With the reappearance of land forms in the Upper Trias we find certain evidence of free migrations again, with the closest relationships between eastern and western forms, none of which could have been derived, immediately at least, from the known American

Permian types. The marine vertebrates of the Upper Jurassic, the next American air-breathers of which we have any knowledge, indicate an advance in specialization over the contemporary forms from the eastern continent, but they also indicate a continued migration of the aquatic forms at least. With the land forms again appearing at the close of the Jurassic and in the Lower Cretaceous, we find strong evidence of a community of faunas, but with a striking absence, hitherto, of some of the smaller forms known from earlier times in the eastern continent. The Upper Cretaceous again shows a belated arrival on the western continent of eastern types, after their advent or even disappearance there. With the exception of certain Triassic marine types, we have no distinctively American Mesozoic groups of air-breathing vertebrates, until we reach the Benton, Niobrara, and Pierre Cretaceous, all indicating a continued, but possibly restricted intermigration between the eastern and western continents during the whole of Mesozoic times. In which way did these migrations occur? That the communication between the two continents in Pennsylvanian time may have been by way of the north Atlantic region is not at all improbable. Indeed, taking into consideration the close relationships known to exist between the European and American type of this period, closer perhaps than existed at any subsequent time during the Mesozoic, this more direct way of communication would seem very probable.

On the other hand, the very close relationships existing between the species of the Proganosauria, hitherto found only in South America and Africa, one genus of which is exclusively American while the other genus, Mesosternum, according to McGregor's recent observations, is represented in both continents by closely allied species, would suggest a close land communication between the two continents during early Permian times at least. That Mesosternum may have reached the two continents, Africa and South America, by the long, roundabout way of the north Atlantic, is hardly possible, for the same freedom of communication would have opened up North America to the ingress and egress of European and American forms. It would seem altogether probable, then, that there not only was a free communication between Africa and South America in Permian times, but that also the communication between North and South

America was closed during the same interval, though of this we cannot be at all sure till we know more of the South American Permian fauna, which, so far, lacks every distinctive form peculiar to North America.

Whether or not the communication between North America and the eastern continents was by way of the north Atlantic, it is quite evident that there must have been free communication during part or all of the Mesozoic time between North and South America, proof of which is seen in the dinosaurs, mosasaurs, and crocodiles, some of them, according to competent observers, identical generically even with North American forms. We have yet much to learn about the Mesozoic fauna of South America, but, so far as our knowledge yet goes, there is a close relationship between them. This similarity, of course, may have been the result of a westward migration from Africa to South America by the way of a southern land communication, and a concurrent intermigration of the same types from Africa northward to Europe and thence by the north Atlantic to North America. But a simpler explanation would be that of a land communication between North and South America, and a single trans-Atlantic bridge, which, in my opinion, was the southern one.

It is very true that such hypotheses as I have offered are largely based upon negative evidence. Future discoveries may bring to light, both in Europe and America, types which now appear to have a more restricted geographical distribution; especially may future discoveries in South America and Africa show more distinctive types, or, on the other hand, more common forms. I do believe, however, that the long-continued exploitation of the Mesozoic rocks of North America is gradually converting negative into positive evidence; that we may say with tolerable certainty that certain types of land vertebrates, such as the Proterosauria, Proganosauria, Pareiosauria, Therodontia, etc., have never existed in North America.

In the accompanying table I have given, as fully and as accurately as the present state of our knowledge will permit, the geological range and distribution of the larger groups of air-breathing vertebrates, with especial reference to North America. In not a few instances precise stratigraphical data are wanting, so that groups must be recorded throughout a division of the chart, which later may be found to have a more restricted range. An attempt has been made to indi-

cate by association the phylogenetic relationships of the groups, but it must be remembered that opinions differ not a little concerning the phylogeny of the reptiles, and those expressed in this chart are merely the ones which seem most reasonable to myself. I am indebted to Dr. v. Huene for a number of suggestions and facts of distribution which have been incorporated in the table; and to Dr. W. D. Matthew I am also obliged for the data for the mammals. It is to be hoped that Dr. Matthew will confer a favor upon us all by publishing soon a complete table of the distribution and range of the mammals; no one is more competent.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

8. LATEST PALEOZOIC NORTH AMERICA[2]

North America during the latest Paleozoic, the period which corresponded in a general way with the Permian in Europe, was an expanding land. On the east the Appalachian peninsula had been eroded during Pennsylvanian time and erosion continued vigorously during the later Paleozoic. The elevation which gave the process of erosion this opportunity was probably due to pressure from the Atlantic, that raised all the eastern margin and exposed any then existing coastal plain, out to the edge of the continental shelf. The pressure ultimately occasioned the displacements apparent in the folded and overthrust zone of the Appalachian and St. Lawrence valleys, and it is probable that the continental margin on the Atlantic side was then moved westward to near its present position, the oceanic basin expanding westward to an equal amount.

In the eastern central United States the area of continental deposits shrank within narrower limits. The condition of the Mississippi embayment is unknown.

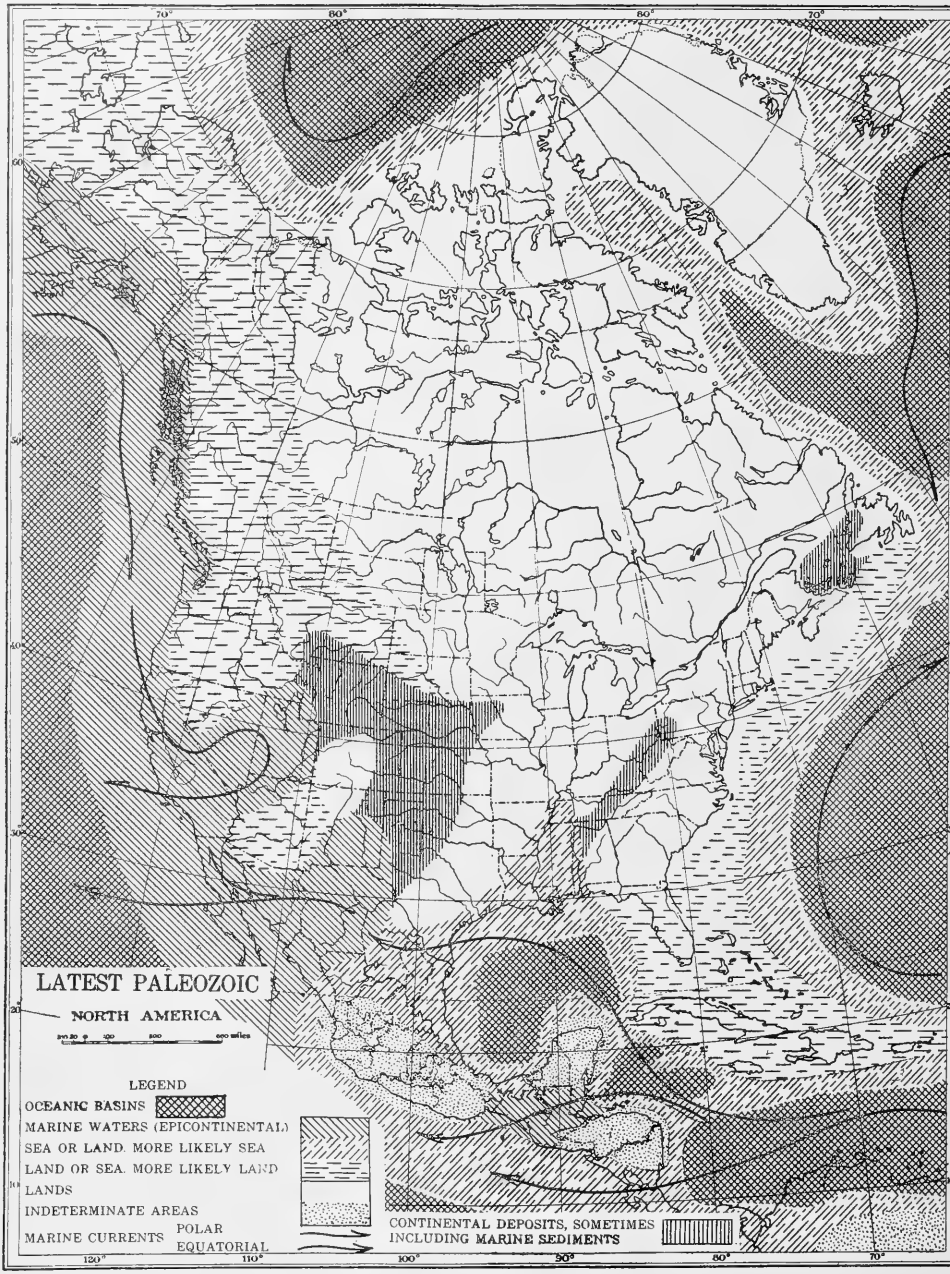
In the northwest the land extended, apparently, nearly if not quite to the Pacific; but in southern Alaska the sea prevailed.

The island which stretched from Colorado to southern Arizona obstructed to some degree the general distribution of the red sediments, chiefly of continental character, which were derived from the wide lands to the northwest, north, and northeast. The island also separated the northern embayment of waters which were probably cool from the southern sea, through which flowed a warm current; and thus it divided two faunal districts.

The geographic conditions and the independent evidence of climatic diversity indicate that the north was cool, if not cold, and the

1 Published by permission of the Director of the U. S. Geological Survey.

2 Map prepared in collaboration with Dr. G. H. Girty.


LATEST PALEOZOIC
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND. MORE LIKELY SEA
LAND OR SEA. MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
120°
110°
100°
90°
80°
70°

south warm. The vertebrates known from Nova Scotia to Texas appear to have lived in the more genial regions and to have had no communication (unless closely following the Pennsylvanian) with Europe or South America, although the latter was connected with Africa by some southern route. The barriers to intermigration in the north may have been marine waters (North Atlantic) and cold climate (Alaska-Siberia).[1]

[1] My thanks are due to Dr. S. W. Williston for discussion of the evidence regarding vertebrates.—B. W.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

9. TRIASSIC NORTH AMERICA

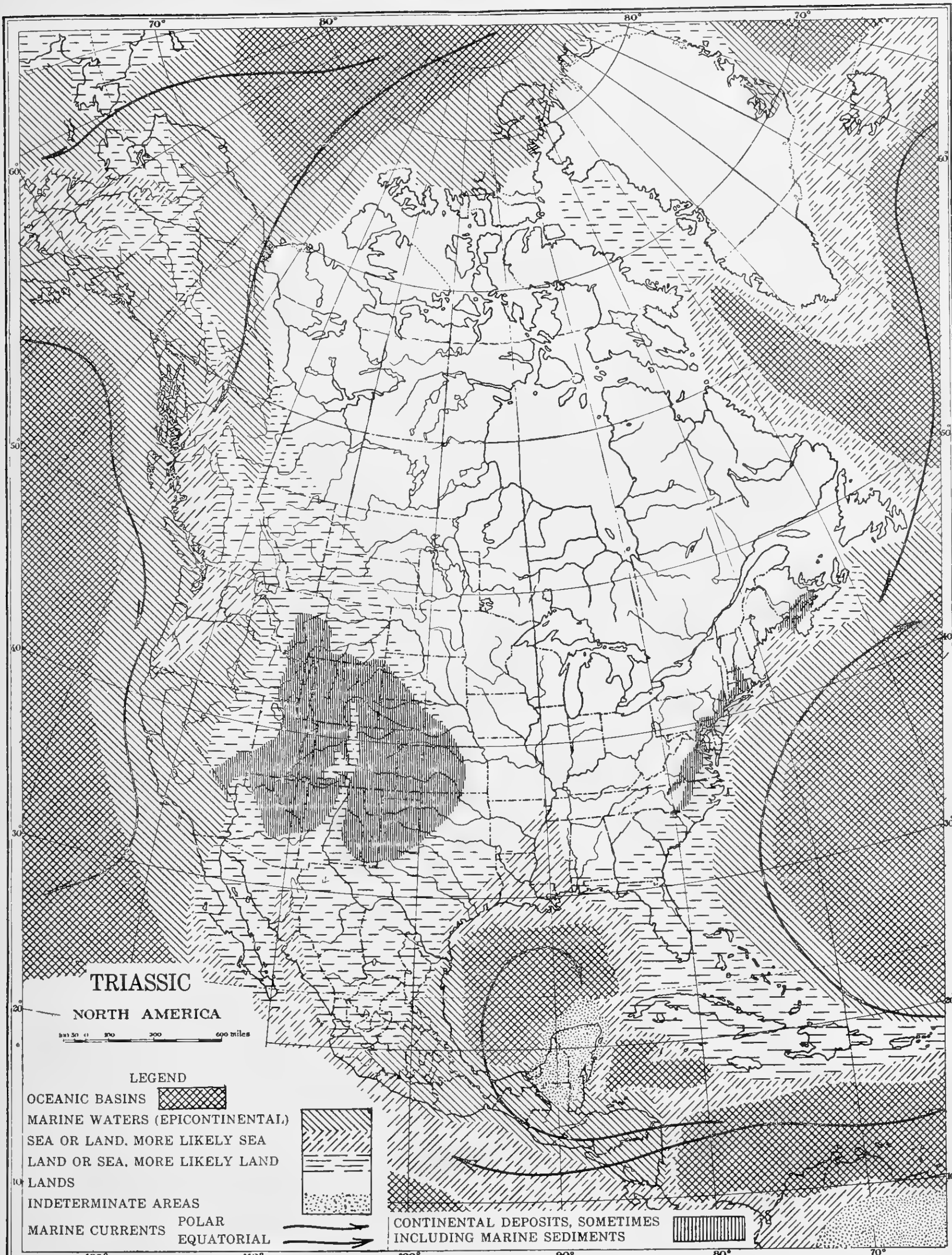
In Triassic time North America attained a larger connected land area than at any known epoch of its earlier history. The eastern region was apparently subject to erosion till the close of the period, when the continental or estuarine deposits of the Newark group gathered in basins near the probable margin.

Lower Triassic marine strata occur in southwestern Idaho in an area mapped as occupied chiefly by continental deposits. The principal epicontinental seas, however, appear to have formed embayments in British Columbia and west of longitude 115° in the United States. They were probably not connected. Southern Alaska was submerged and Behring Strait also.

With the close of the Triassic the embayments upon the continental plateau appear to have become land and the continent attained in the early Jurassic a still greater expansion. Both eastward and westward it exceeded its present coasts in middle latitudes and no part of the intervening continent was submerged.

The Triassic continental deposits indicate an arid climate in the central west; whereas on the southeastern Atlantic border there was a humid climate in which marsh conditions prevailed.

[1] Published by permission of the Director of the U. S. Geological Survey.


TRIASSIC
NORTH AMERICA
600 miles
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
70°
80°
80°
70°
60°
50°
40°
30°
20°
10°
120°
110°
100°
90°
80°
70°

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

10. LATE JURASSIC NORTH AMERICA[2]

The very extensive land area which North America presented during a part of the Jurassic period was reduced in the late Jurassic by marine invasion from the Pacific. The sea transgressed to western Nevada. It apparently occupied much of British Columbia, but the subsequent intrusion of the great batholith of the Coast Range destroyed the record near the coast. Further inland volcanic effusive rocks are associated with marine sediments, which on meager paleontological evidence are classed by Stanton as probably Jurassic and by Whiteaves as "Lower" Cretaceous.

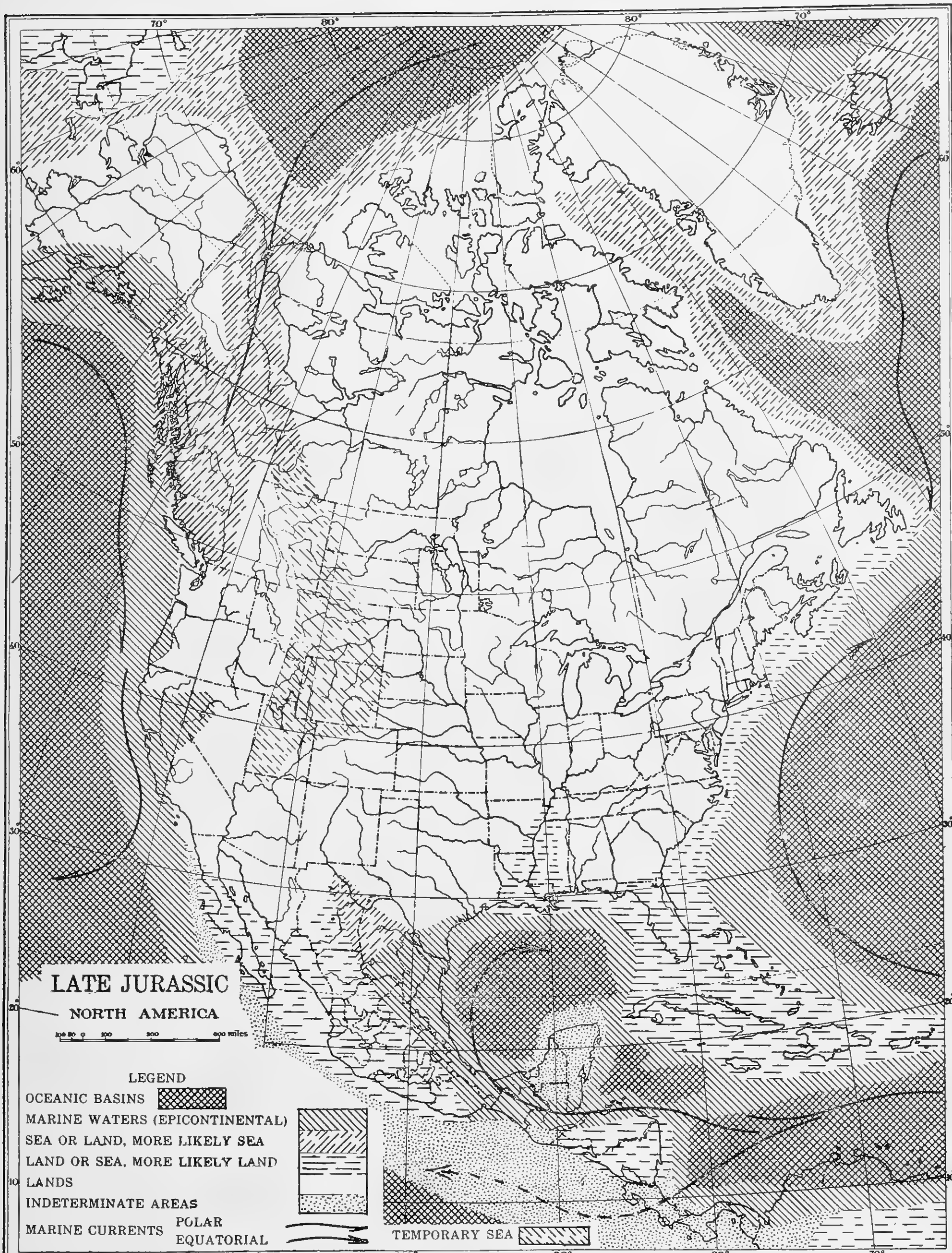
Communication of Pacific waters through the Arctic with the seas of eastern Europe and Asia is indicated by similar boreal species in both regions, but the connection is not known. It may have been by Behring Sea, as Stanton thinks probable, or by the Mackenzie, as Willis infers.

Marine waters (the Sundance sea) extended temporarily to Dakota, Wyoming, and southern Utah.

On the east the continent was low. The lower part of the Potomac formation, long considered to be late Jurassic, is according to the latest work under W. B. Clark probably "Lower" Cretaceous (Comanche). The limit of the coastal plain is therefore unknown. It was beyond the present coast.

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Map prepared by Dr. T. W. Stanton; modified, as regards marine connection between the Pacific and the Arctic in the Mackenzie Valley, by Bailey Willis.


LATE JURASSIC
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY SEA

SUCCESSION AND DISTRIBUTION OF LATER MESOZOIC INVERTEBRATE FAUNAS IN NORTH AMERICA

T. W. STANTON

IX

EARLIER MESOZOIC FAUNAS

In early Mesozoic time the marine invertebrate faunas of North America were closely confined to the borders of the present continent, and particularly to the western border. The land-area, or at least the area above sea-level, was nearly as large as it is now. The early Triassic sea with a rich ammonite fauna extended as far as eastern Idaho but its area was apparently restricted and its most probable connection with the ocean was through Utah, Nevada, and southern California. Later Triassic marine faunas are not known east of western Nevada and eastern Oregon in the United States. They occur also at many localities in British Columbia and Alaska, and in a very limited area near Zacatecas, Mexico. The occurrence of fresh-water shells (Unio) in the Upper Triassic of New Mexico, and the character of the vertebrate remains found there and at other points farther north, attest the non-marine character of the Triassic deposits in the Rocky Mountain region. The scanty invertebrates found in the Newark group of the east also indicate non-marine deposits. Early Jurassic (Liassic) faunas are apparently restricted to an area still smaller than that of the marine Trias.[1]

LATE JURASSIC FAUNAS

Marine fauna.—At or near the close of the Middle Jurassic the sea again invaded the continent and covered a large part of the Rocky Mountain region. It extended east to the Black Hills, south to southern Utah, and covered much of Montana, Wyoming, and Utah, with the northwest corner of Colorado, part of Idaho, and a considerable

[1] A full discussion of the marine Trias may be found in the published writings of Professor James Perrin Smith. See especially *Proc. Cal. Acad. Sci.*, 3d Ser., "Geology," Vol. I, No. 10, 1904; and *Von Koenen Festschrift*, pp. 377–434, 1907.

area in British America. The fauna of this Rocky Mountain Jurassic sea is characterized by *Cardioceras cordiforme*, Cadoceras, *Belemnites densus*, and a rather varied though not large fauna consisting mostly of bivalves. It has long been recognized by Neumayr and others to be of boreal type and hence as indicating a connection either direct or indirect with the Arctic region. The fauna shows some local variations, usually associated with variations in the character of the sediments; but it appears to be essentially a unit throughout the entire area. It is believed that the deposits were all formed in one basin and within a comparatively brief period. Their maximum thickness is usually only a few hundred feet.

As there are no other marine Jurassic formations in the region and the section is known to be incomplete it is necessary to go to other areas where similar faunas occur to determine the exact position of this one in the general column. In the Upper Jurassic the following stages are recognized by De Lapparent who gives them universal application:

Portlandian { Purbeckian / Bononian }
Kimmeridgian
Sequanian
Oxfordian
Callovian

The Jurassic of the Rocky Mountain region, as far as can be determined from the fauna, represents the Oxfordian and perhaps the Callovian in whole or in part. That is, it is the lower part of the Upper Jurassic. In a large part of its area it rests on the Carboniferous, and the youngest marine fauna found beneath it anywhere is in the Lower Trias, while the oldest succeeding marine fauna is Upper Cretaceous. It is obvious, therefore, that neither the ancestors nor the descendants of its species are found in the same area, but fortunately its stratigraphic position is fairly well determined in the much fuller Alaskan section. On the shores of Cook Inlet the Middle and Upper Jurassic are represented by about 10,000 feet of strata with at least three distinct marine faunas[1] which are largely still undescribed. The strata have been almost equally divided into the

[1] Stanton and Martin, "Mesozoic Section on Cook Inlet and the Alaskan Peninsula," *Geol. Soc. Am. Bull.*, Vol. XVI, pp. 391–410.

Enochkin formation below and the Naknek formation above. The upper part of the Enochkin formation is characterized by a great development of the ammonite genus Cadoceras, indicating the boreal facies of the Callovian stage, while the Naknek formation contains Cardioceras near the base and an abundance of Aucella with Lytoceras, Phylloceras, etc., in the overlying beds. The fossils indicate that the horizon of the Rocky Mountain Jurassic is near the boundary between the Enochkin and Naknek formations. In other words this Rocky Mountain epicontinental sea, which W. N. Logan has discussed,[1] was drained before the deposition of the Jurassic "Aucella beds" which have such a great development in Alaska and farther south on the Pacific coast as well as in Russia and in many areas of the boreal region. Its fauna is clearly boreal, as has already been stated, and there was marine connection either directly with the Arctic Ocean, or, as the known distribution of the rocks makes more probable, indirectly through the north Pacific somewhere between Vancouver Island and Cook Inlet. There seems to have been no direct connection with the contemporaneous sea of California which had a different, though imperfectly known, fauna more closely related to middle European faunas.

After the sea had retreated from the Rocky Mountains the boreal Aucella fauna which occurs in the Naknek formation extended down along the Pacific coast into Oregon and California where it characterizes the Mariposa slate and equivalent formations, continuing through a great thickness of strata to the top of the Jurassic and passing without any striking change into the Lower Cretaceous.

In Mexico no faunas are known that belong to the Middle Jurassic, or to the Callovian and Oxfordian stages of the Upper Jurassic, but the later stages, or at least the Kimmeridgian and Portlandian, are well represented near Mazapil in the state of Zacatecas and in adjacent portions of neighboring states. Burckhardt who has recently described the fauna[2] states that it resembles the faunas of central Europe and the Mediterranean but that it also contains forms that show relationship with the Russian or boreal fauna and others that connect it with the Jurassic of the South American Cordillera. He

[1] *Jour. of Geol.*, Vol. VIII (1900), pp. 241–73.

[2] Instituto Geológico de Méjico, *Boletín No. 23*, 1906.

concludes that there must have been direct marine connection with all these regions. The most striking example of the introduction of a new element in the fauna is the intercalation of a thin Aucella bed in the midst of strata containing the Mediterranean type of fauna in the upper Kimmeridgian. The Aucella must have come in from the Pacific where, as we have seen, the boreal type of fauna extended at least as far south as middle California. The nearest recorded occurrences of Aucella in the other direction are on the east coast of Greenland and in England. On the other hand this Mexican fauna as a whole is so unlike that of California and so related to that of Europe, and the geographic position of the beds is such that connection with the Gulf of Mexico seems most reasonable. The area should therefore be mapped as included in the Atlantic sedimentation though it is probable that the Pacific waters bearing the Aucella found temporary access to it from some point south of the Gulf of California. If the exact position of this temporary Pacific connection is still indicated by sediments they have not yet been recognized.

Farther south in Mexico a somewhat different facies of the Upper Jurassic fauna found in the state of Oaxaca has been described by Felix[1] but according to Cragin[2] this has some species in common with the Malone Jurassic fauna of western Texas which on the other hand shows some relationship with the fauna of Catorce, San Luis Potosi, and hence also with that of Mazapil. The Malone fauna shows no connection whatever with the Rocky Mountain Jurassic because it belongs to a later stage and to a different province. It probably lived in an arm of the Gulf of Mexico directly connected with the area in Zacatecas and San Luis Potosi, and including the locality near Cuchillo Parado, Chihuahua, reported by Aguilera.[3] Some of the elements of the Malone fauna show decided Cretaceous affinities and thus strengthen the evidence that it is latest Jurassic.

In Europe Neumayr recognized three marine faunal provinces in the Jurassic which, as he believed, indicated climatal zones. These are the Mediterranean or Alpine, the Middle European, and the boreal

[1] *Palaeontographica*, Band XXXVII (1891), pp. 172–80.

[2] U. S. Geol. Surv., *Bull. 266*, 1905.

[3] *Aperçu sur la geologie du Mexique*, p. 8, 1906.

or Russian, each characterized by different types of ammonites and other invertebrates. For example, the ammonite genera Lytoceras and Phylloceras are abundant in the Mediterranean province, occur sparingly in the Middle European, and are practically absent from the Russian Jura. Coral reefs and important limestones also are not found in the boreal Jurassic formations.

In America there is no difficulty in recognizing a boreal fauna in the Upper Jurassic which, as we have just seen, temporarily extended far south in the Rocky Mountain region and at a later stage still farther south along the Pacific coast. It is like the Russian fauna in its essential features although it does contain the Mediterranean types Lytoceras and Phylloceras in Alaska. There is likewise no difficulty in recognizing a southern or Mexican fauna in which are commingled many of the types which in Europe are separated and considered characteristic of the Middle European and Mediterranean provinces. Finally the Mexican fauna received by way of the Pacific a few immigrants from the boreal fauna.

Variations in the lithologic development are worthy of note. Limestones form a large proportion of the sediments in Mexico while they are relatively inconspicuous in all the areas where the boreal fauna is dominant.

Jurassic (?) freshwater fauna.—The marine Jurassic beds throughout the Rocky Mountain region of the United States are immediately overlain by the continental freshwater or marsh deposits of the Morrison formation which also extend south through Colorado into New Mexico beyond the limits of the marine Jurassic beds. Its large and varied dinosaur fauna was originally assigned to the Jurassic without question, but during the last few years some paleontologists have referred it to the Cretaceous. Its stratigraphic position is consistent with either reference as the interval otherwise unrepresented comprises a considerable part of each system. Its invertebrate fauna consists of several species of Unio, Vivipara, Planorbis, etc., all of modern freshwater types which do not assist in discriminating between Jurassic and Cretaceous. The fact that the Morrison is overlain by the Kootenai on the north and by the marginal deposits of the Comanche on the south tends to place it early in the transition interval.

EARLY CRETACEOUS FAUNAS

At the beginning of the Cretaceous the two faunal provinces which have just been indicated were even more sharply defined than they had been in the Jurassic, and in each area the characteristic elements of the fauna are developed from the fauna that preceded it. The Shasta fauna on the one hand and the Comanche fauna on the other are always sharply contrasted, though each exhibited several facies. When compared with European faunas, one is in the beginning chiefly boreal and the other Mediterranean; one is associated with shales, sandstones, and conglomerates, the other, mainly with limestones.

Shasta faunas.—The boreal Aucella fauna of the Knoxville formation is the earliest one in the Shasta series. It is distributed from the Arctic coast of Alaska to southern California but south of the Yukon never extending as far east as the late Jurassic fauna did. Cretaceous Aucella beds have been reported from Catorce, San Luis Potosi, Mexico, but it is probable that these are Jurassic on about the same horizon at which Aucella occurs at Mazapil.

The succeeding Horsetown fauna though at first showing a transition from the Knoxville fauna is, as a whole, remarkably distinct from it. It is characterized by the great abundance and variety of ammonites of types which in Europe are considered distinctive of the deeper water facies of the Mediterranean province. The boreal element is wanting, or at least inconspicuous. This early Horsetown fauna is much less widely distributed than the Knoxville. In its typical development it is known in a relatively small area in northern California and in Oregon. Toward the close of the Horsetown the fauna was greatly modified by the introduction of many types that show relationship with the Cretaceous faunas of southern India and also with those of Japan. This relationship was continued in the succeeding Upper Cretaceous faunas to such an extent that it is appropriate to speak of an Indo-Pacific province or region. This later Horsetown fauna was more widely distributed along the Pacific border and is well developed as far north as the Queen Charlotte Islands.

The marked change at the close of the Knoxville when the fauna ceased to have a distinctively boreal character was probably due to a northern uplift which closed Bering Strait and other direct connections

between the Arctic and Pacific Oceans. The closing of these connections would modify the currents, change the climate, and permit immigration of faunal elements from other areas without any other geographic changes.[1]

Comanche faunas.—The whole of the Comanche series is here treated as Lower Cretaceous, because in the Texan area the top of the Comanche is the only natural and satisfactory major plane of division in the Cretaceous. Stratigraphic, lithologic, and paleontologic studies all lead to the same conclusion. Many European paleontologists believe that the upper or Washita portion of the Comanche is of Cenomanian age and hence referable to the Upper Cretaceous of European standards and the Mexican geologists, while adopting this view, advocate for their country a threefold division of the Cretaceous and call the upper part of the Comanche, including the Fredericksburg and Washita groups, Middle Cretaceous. These varying views as to the classification and correlation of the formations are not important in the present discussion of the succession and distribution of the faunas which are grouped under the term Comanche. These faunas show many facies varying from time to time and from place to place. There are littoral faunas, reef faunas, and deeper-water faunas, but the reef facies is perhaps the most striking and characteristic. And yet these different facies are all so intimately connected either by common species or by stratigraphic relations that it is appropriate to speak of the Comanche fauna as a whole. When the Comanche fauna is examined either as a whole or in detail it proves to be very similar to the Cretaceous fauna of the Mediterranean province in southern Europe, and it is strikingly contrasted with the Shasta fauna of the Pacific coast, although the Comanche area in Mexico closely approaches the present Pacific coast throughout that country. On a previous occasion I have called attention to the character of the differences between the Shasta and Comanche faunas.[2] They are not made up of related forms differing specifically, but they consist mainly of different classes of animals so that they present

[1] See *Von Koenen Festschrift*, p. 433, where J. P. Smith has suggested that periodic opening and closing of these connections are sufficient cause for the changes in Mesozoic and later faunas of the Pacific coast.

[2] *Jour. of Geol.*, Vol. V (1897), p. 608.

totally different facies, bespeaking very dissimilar conditions. If there had been direct and free marine connection between the two areas it is probable that the conditions could not have been so different and the faunas would have shown less contrast. That the two faunas were approximately contemporaneous and that there was no important break in the sedimentation of either area during this epoch are well determined facts. It is believed, therefore, that there was a long land mass approximately parallel to the present west coast separating the two provinces.

In considering the Comanche area, as mapped, it should be remembered that a long period during which thousands of feet of limestone were formed is represented, and that the sea was advancing toward the north. The best-known early Comanche fauna is found near Tehuacan in the state of Puebla. It has been suggested with some reason that this is possibly in part somewhat older than the Trinity group which forms the base of the Comanche in Texas. It is largely a reef fauna consisting of corals and other sessile animals with other forms that are usually associated with them. Farther north one facies of the Trinity group fauna is characterized by an abundance of Orbitolina, while another facies has more of a littoral character. Trinity strata and fossils are found as far west as Bisbee, Arizona, and north to southwestern Arkansas and southern Oklahoma.

The succeeding fauna of the Fredericksburg group also has both littoral and reef facies. The latter is characterized by an abundance and great variety of Rudistae, Chamidae, and Caprinidae with Nerinea, etc., usually occurring in very pure limestone, but this facies is in some areas repeated in the Washita group so that the two faunas are sometimes hard to distinguish. The reef facies does not reach the northern boundary of Texas and the Fredericksburg fauna as a whole is not definitely recognized beyond that line though it is possibly represented at the base of the Kiowa shale of southern Kansas.

The reef facies of the Washita fauna is not found north of southern Texas but the littoral facies extends far beyond the limits of the Trinity and the Fredericksburg into northeastern New Mexico, southern Colorado, and middle Kansas. The thin Comanche deposits in all these areas belong exclusively to the Washita group and probably to the upper Washita. They rest at some localities on the

Morrison formation and in others on older formations down to the Carboniferous. They are always directly overlain by the Dakota sandstone.

Early Cretaceous freshwater faunas.—The Morrison fauna which may possibly be Cretaceous has already been referred to in discussing the Jurassic. The coal-bearing Kootenai formation of southern Canada and Montana which is determined by its stratigraphic position and by its flora to be Lower Cretaceous has yielded a few Unios and freshwater gastropods, mostly of simple modern types. These, like the similar forms in the Morrison, are interesting chiefly from the fact that they were probably the direct ancestors of some of the modern American freshwater forms, their successors having been preserved in the rivers of the adjacent land whenever the larger area previously occupied by them was submerged in the sea.

LATER CRETACEOUS FAUNAS

Chico fauna.—On the Pacific coast the Horsetown fauna is succeeded by the littoral Chico fauna which is distributed from the Yukon River to Lower California, occurring on the lower Yukon, the Alaska Peninsula, Queen Charlotte and Vancouver islands, in middle and southern Oregon, in the Sacramento valley and the coast ranges of California to San Diego, and on the peninsula of Lower California as far south as latitude 31° 30′. There are considerable local variations in this fauna as would be expected in view of its great range in latitude. The assemblage of forms found on the Yukon is quite different from that occurring in the Sacramento valley, and still another facies is found in southern California, but these are all connected by common species so that there is no hesitation about referring both the northern and the southern facies to the Chico fauna. The fauna as a whole, like the later Horsetown fauna, is Indo-Pacific in its affinities, and is strikingly different from the faunas of the Atlantic border and interior regions of North America. Whiteaves[1] and F. M. Anderson[2] have argued for a connection during Chico time between the Pacific and interior seas, but the evidence brought forward in support of this view is based on types that have a world-wide distribution and on those that are only similar, not specifically identical.

[1] *Mesozoic Fossils*, Vol. I (1879), pp. 186–90.

[2] *Proc. Cal. Acad. Sci.*, 3d Ser., Vol. II (1902), p. 59.

In my opinion direct connection has not been proved. In time range the Chico fauna apparently began somewhat earlier and continued somewhat later than the Colorado fauna of the interior sea but it did not extend to the end of the Cretaceous, and latest Cretaceous time is probably not represented by marine deposits on the Pacific coast.

Colorado fauna.—On the Atlantic side of the continent and in the interior region the greatest marine invasion of Mesozoic time occurred after the close of the Comanche. The sedimentation began with the Dakota sandstone but the first distinctive marine fauna is found in the overlying Benton shale of the Colorado group. The Colorado fauna as a whole is easily distinguished, although it is developed in several distinct faunal zones and local facies. It is characterized by *Inoceramus labiatus* and several other specific types of Inoceramus, by certain forms of Scaphites, and by the keeled ammonites known as Prionotropis, Prionocyclus, and Mortoniceras, which are sometimes referred to Schloenbachia in the broad sense. The fauna has a very great distribution, extending from Mexico and Texas throughout the Great Plains and Rocky Mountain regions as far north as Peace River in Canada. It is considered probable, though the faunal evidence is too meager for positive assertion, that there was marine connection entirely through from the northern interior to the Arctic Ocean. No marine faunas of Colorado age are known in the Atlantic and Gulf borders east of western Arkansas, unless possibly the imperfectly known fauna of the Eutaw or "Tombigbee" sand of Mississippi belongs to its latest phase. If the Colorado sea covered that area its deposits have been overlapped by later beds. The earliest marine fauna, that of the Magothy or "Cliffwood," in New Jersey, is apparently later than Colorado.

In the eastern and southeastern parts of the Colorado sea where the later Colorado deposits are calcareous, constituting the Austin chalk and the Niobrara formation, the fauna of these beds is different in character from that of the underlying Benton shale, and the Austin fauna is much larger and more varied than that of the Niobrara though their correlation is fixed by a sufficient number of identical species. The calcareous Niobrara is characteristically developed east of the mountains in Colorado and Kansas, and northward to the Black Hills and Manitoba, but farther west and northwest the

Niobrara is represented by shale, and is not lithologically separable from the Benton. The fauna is here correspondingly modified and a number of Niobrara and Austin species are associated with an assemblage of other forms peculiar to the region, together with a few that show closer relationship with the Benton fauna.

A horizon near the top of the Benton in Texas, New Mexico, and southern Utah is characterized by an abundance of ammonites belonging to the genus Metoicoceras Hyatt, formerly referred to Buchiceras, together with a number of other forms not known elsewhere. A littoral facies of the Benton fauna is developed in Utah and western Wyoming, and locally in southern Colorado, associated with sandstones and, except in Colorado, with coal-beds.

These local or temporary differences in the Colorado fauna may be attributed to differences in depth, in proximity to the shore, and possibly to variations in climate conditioned on ocean currents. With a shallow sea and an open connection with the Arctic the southern local facies in the Benton and the Niobrara would probably correspond with the area directly influenced by the equatorial or gulf current. Certain important forms, however, like *Inoceramus labiatus* and *Prionotropis woolgari* are distributed throughout the entire area.

In the Athabasca region of northwestern Canada a peculiar ammonite fauna has been described from the Peace River sandstone, and the Loon River and Clearwater shales, all of which are referred to the Colorado group; but the question of their age and relationship should be left open until the geology and paleontology of the region are known more in detail. It has been suggested that they may be older than Colorado.

Montana fauna.—From New Mexico northward the Montana group has nearly the same distribution and extent as the Colorado group. It varies greatly in character, from all marine in some areas to largely brackish and freshwater deposits in others, and its faunas are correspondingly differentiated. A considerable element of its marine fauna is evidently derived directly from the Colorado fauna but a large proportion of it is apparently composed of immigrants from other areas, probably in part Arctic and in part Atlantic. In the north a littoral facies associated with sandstones and a deeper-water facies (the Pierre fauna) in shales may be distinguished. The littoral

facies is typically developed in the Fox Hills sandstone at the top of the group but a closely similar fauna occurs at several lower horizons.

Ripley fauna.—Toward the south in New Mexico the littoral facies of the Montana fauna blends with the Ripley fauna which is well developed in the latest Cretaceous formations of Texas, Mississippi, and Alabama, and throughout the Atlantic coastal plain to New Jersey. The Ripley and Montana faunas have many species in common and many others that are closely related and yet their aspect is unlike because their dominant types are different. In the Montana fauna the genus Inoceramus is very abundant and varied and ammonoids—especially Placenticeras, Baculites, Scaphites, and other evolute types—are abundant while the Ostreidae, Veneridae, Cardiidae, etc., and gasteropoda play an unimportant rôle. In the Ripley fauna on the other hand ammonoids and Inoceramus are relatively rare and the Ostreidae, Veneridae, Cardiidae, and many types of gasteropoda, including Volutidae, are greatly developed. The Ripley fauna is more varied and luxuriant, so to speak, than the Montana and apparently indicates a warmer, or at least a more favorable climate. There was almost certainly direct connection between the areas occupied by the two faunas, but the life conditions were sufficiently different to determine distinct faunal facies. The Montana fauna probably received some of its elements directly from the Arctic, while the Ripley fauna came in from the Gulf of Mexico and the Atlantic. With the connection between the Atlantic and Pacific closed in the Mexican and Central American region as at present, the Gulf stream would give similar conditions and would distribute the Ripley fauna along the coast from Texas to New Jersey. It is noteworthy that the European fauna most closely related to the Ripley is found at Aachen in Germany and that the most natural route of migration, with such a configuration of the continent as is here assumed, would be from the American Atlantic coast northeastward to Europe.

A peculiar Cretaceous fauna, apparently contemporaneous with the Ripley, has recently been described by Böse[1] from Cardenas, San Luis Potosi, Mexico. It contains a few typical Ripley species like *Exogyra costata* and *Gryphaea vesicularis*, together with many

[1] Instituto Geológico de Méjico, *Boletín No. 24*, 1906.

corals, Rudistae, Actaeonella, etc., which suggest the Cretaceous of Jamaica. It may be considered a reef facies of the Ripley fauna.

All the late Cretaceous marine faunas that have been briefly mentioned are still typically Mesozoic, although it is true that they contain many generic types that continue on through the Tertiary. The succeeding Tertiary faunas, whether on the Pacific coast, the Gulf border, or the Atlantic coastal plain, show a very striking change from the Cretaceous faunas that immediately precede them. The specific types are practically all different.

Non-marine later Cretaceous faunas.—In the Rocky Mountain region throughout later Cretaceous time there was a great development of freshwater and brackish-water deposits alternating with marine formations. They are usually coal-bearing, and yield invertebrate faunas frequently associated with land vertebrates and plants.

The invertebrate fauna of the Dakota sandstone is too meager to be of much value. It consists of a few brackish-water species with Unio and a few other freshwater shells in other strata and at the top some marine species that probably really belong with the succeeding Colorado fauna. The freshwater species show relationship through the genus Pyrgulifera with the fauna of the Bear River formation which is apparently about on the horizon of, or a little later than, the Dakota. The Bear River fauna is distributed over a considerable area in southwestern Wyoming, and is unique among western non-marine faunas in that it contains a number of types that have left no descendants in later formations of the region. The most distinctive forms are freshwater species, but the fauna also contains brackish-water elements. The submergence beneath the Colorado sea which immediately followed the deposition of the Bear River formation seems to have been so complete in this region that the freshwater forms were not able to survive. But in the Colorado group itself along the western margin of the sea, especially in Utah and western Wyoming, there are intercalations of coal-bearing beds which contain a few Unios and other freshwater shells and brackish-water types like Ostrea, Anomia, Corbula, and Modiola, some of which recur in identical or closely similar forms at several horizons to the top of the Cretaceous.

In the Montana group there are local more or less distinctive non-

marine faunas in the Mesaverde, Eagle, Claggett, and Judith River formations. The last-named formation in its typical area has a considerable fauna with a number of species that are not known in other horizons, associated with others of wider range.

The Laramie fauna, which is the last of the conformable Upper Cretaceous series, does not differ materially from the non-marine faunas that preceded it except in specific details. The brackish-water and freshwater elements of its faunas are, of course, seldom mingled in the same stratum but alternate with each other. The brackish-water species have survived from earlier formations in the same region by living in the marine waters or advancing with the sea margin when the submergence came. The freshwater types must have been preserved in the streams of the adjacent lands when marine or even brackish waters covered the larger part of their habitat. A considerable number of freshwater types were thus enabled to survive into the Tertiary and there are some Laramie *species* that continue without perceptible change in the Fort Union or earliest Eocene. With the brackish-water forms of the Laramie the case is different. They could not exist for any appreciable period much above sea-level and when the final uplift came that drained the interior region and brought the Cretaceous to a close, the last oysters and other brackish-water mollusks of the interior region died. Hence in areas of non-marine deposition where the line between Cretaceous and Eocene has not been sharply drawn, because the erosion plane that is supposed to separate them has not yet been located, the occurrence of an oyster-bed, or a stratum full of Corbula, is sufficient evidence that the rocks are still Cretaceous and below the major unconformity that separates Cretaceous from Tertiary.

The very few freshwater shells that are known from the Denver and Livingston formations in their type areas are not distinctive, but the beds which bear the Triceratops vertebrate fauna in Converse County, Wyoming, and the strata with the same vertebrates in eastern Montana, locally known as the "Hell Creek Beds," have a highly differentiated molluscan fauna of Unios, and other freshwater shells which is much more closely related to the preceding Cretaceous faunas than to that of the typical Fort Union which follows. The evidence of the invertebrates as well as of the vertebrates is strongly in favor of assigning these so-called "post-Laramie beds" to the Cretaceous.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

II. LOWER CRETACEOUS (COMANCHEAN) NORTH AMERICA[2]

In passing from the Jurassic to the Lower Cretaceous North America underwent but little change along the Atlantic border and throughout the east. It remained a low land and the coastal plain was somewhat more deeply submerged. But on the Pacific coast, on the contrary, there was pronounced movement, particularly in the Coast Range of California. A bold peninsula developed from Oregon south to Santa Barbara and, being eroded, yielded the thick sediments of the Shasta group, which were deposited in marine water east of it, in part.

In Alaska the Shastan sea appears to have invaded the Jurassic land widely, but the details are not yet known.

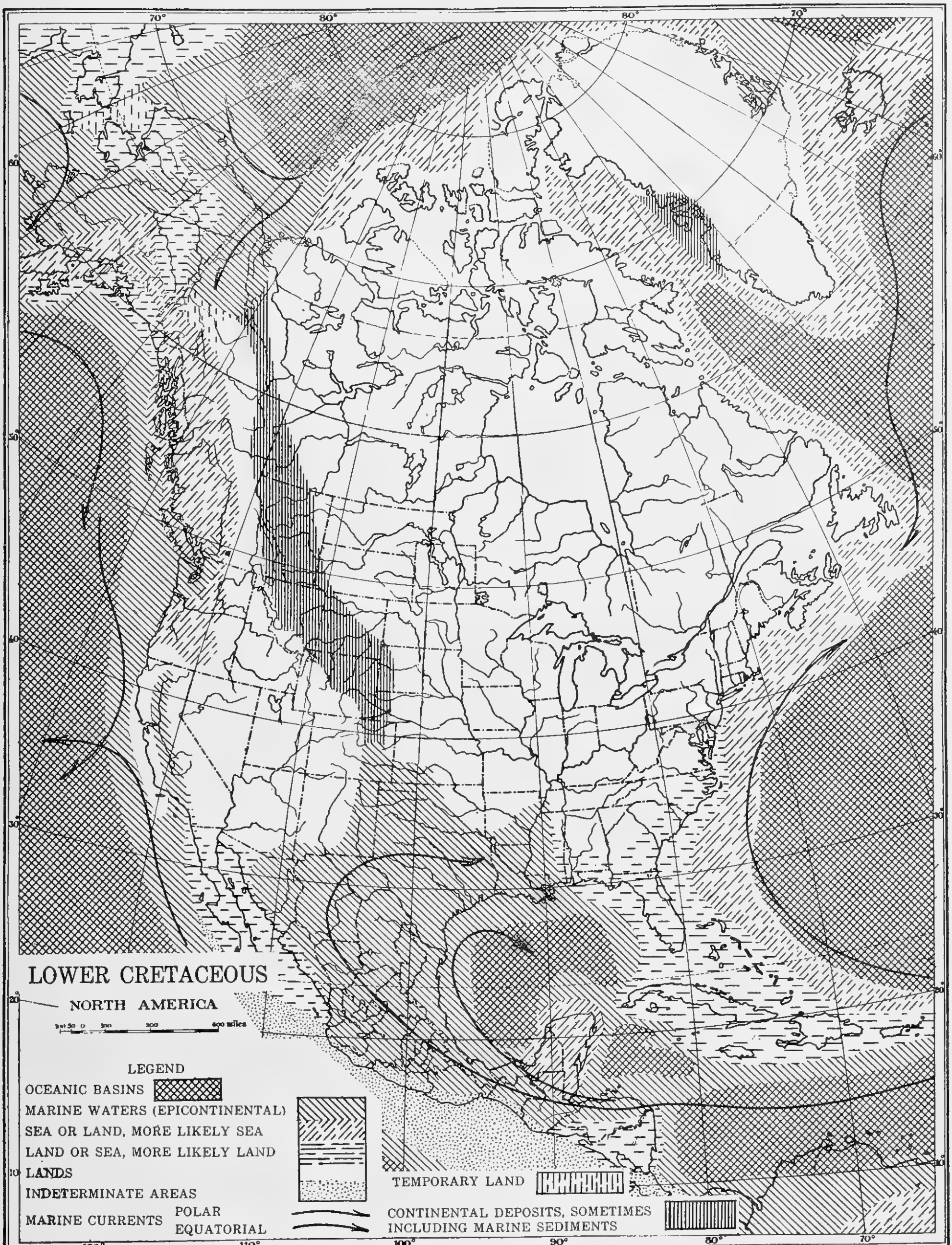
On the east of the Cordillera, from British Columbia to Wyoming, coal-bearing continental deposits (Kootenie) accumulated in a deepening trough. In Wyoming, Dakota, and Nebraska a deposit of sand (Lakota) was spread upon the plain. South of this occurs the much older Morrison formation, which is regarded as probably Jurassic by Stanton and which is overlapped by the marine Comanchean strata of the gulf. The Kootenie, Lakota, and Morrison are comprised in the area mapped as continental deposits.

The striking feature of Comanchean geography is the expansion of the Gulf of Mexico toward the west and northwest and the deep subsidence of its floor, upon which accumulated a remarkable thickness of limestone. The unusual calcareous deposit of organic remains indicates the rich life of an equatorial ocean current.

The fauna of the Gulf of Mexico in Comanchean time is entirely unlike that of the Pacific coast. No adequate explanation of this fact has been suggested except that a land mass diverted the ocean current. The position of the supposed land was southwest of Mexico and is indicated by the dotted area.

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Map prepared in collaboration with Dr. T. W. Stanton.


LOWER CRETACEOUS
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
TEMPORARY LAND
CONTINENTAL DEPOSITS, SOMETIMES
INCLUDING MARINE SEDIMENTS

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

12. UPPER CRETACEOUS NORTH AMERICA[2]

North America was submerged over extensive areas during the Upper Cretaceous. From Cape Cod to Texas the Atlantic and Gulf coasts of the preceding period were transgressed by the sea. From the Gulf to the Arctic marine waters spread over what is now the site of the Great Plains and in the United States that of the Rocky Mountains. The Pacific extended its limits in California and Oregon; farther north, however, from British Columbia to Alaska the land gained.

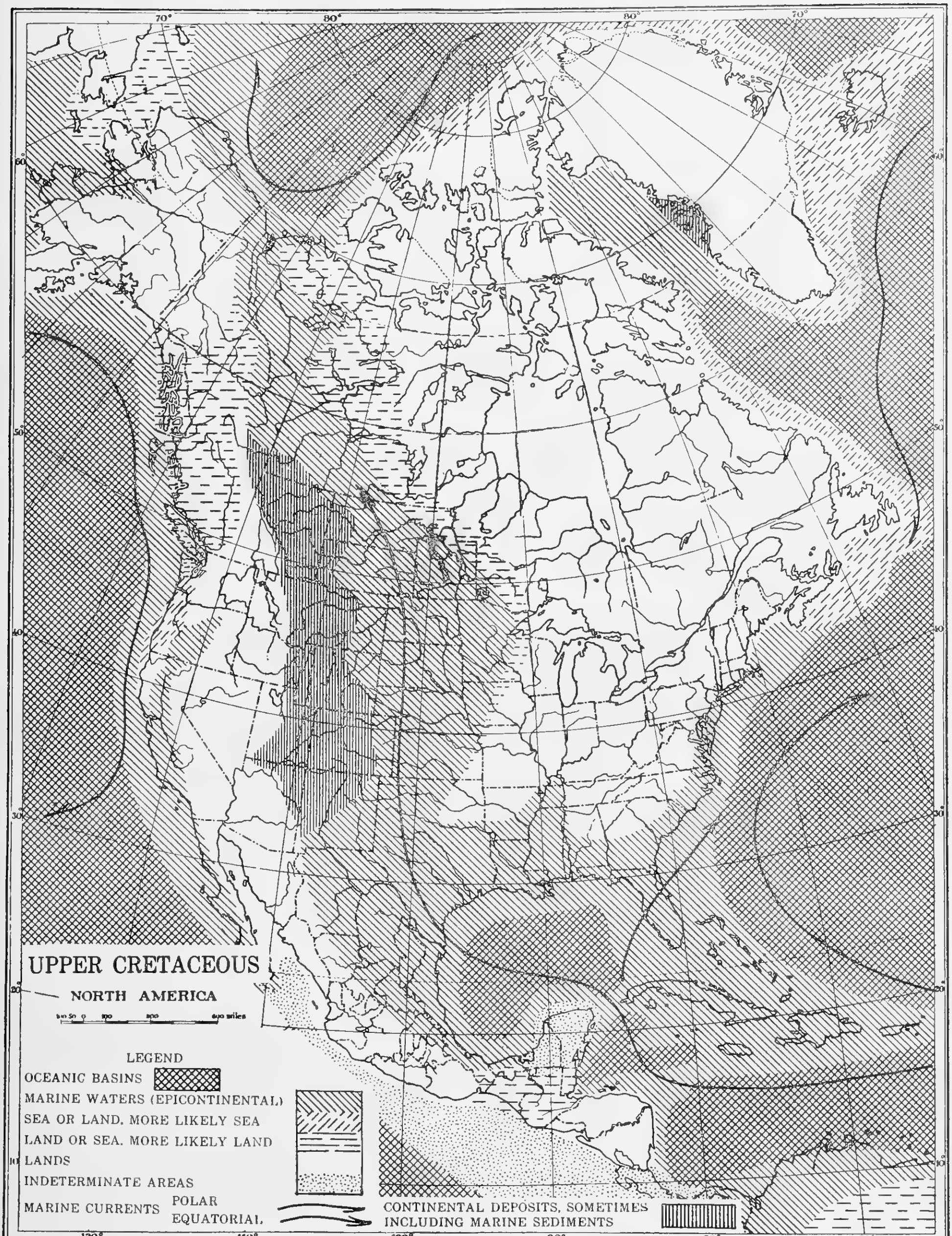
In the central West, from New Mexico to Alberta the invasion of the sea was followed by emergence of the area ruled on the map for continental deposits. The surface of the area was built up by sediments which were derived from uplands west of it, and which accumulated about as fast as the bottom sank. The area thus formed a coastal plain, extensive marshes prevailed, and the marsh deposits eventually became coal beds. Sea, marshes, and river plains alternated in sequence till near the close of the Cretaceous period, when in this Rocky Mountain area certain spots became mountains, the forerunners of the Colorado Front Range, the Black Hills, and Bighorn Mountains of today.

East of the Rocky Mountain coastal plain the marine strait prevailed to the end of the period. It divided the continent, reduced the northern land area, and admitted warm waters to the Arctic. These conditions favored the mild climate which the northern regions then enjoyed.

The eastern portion of the continent contrasted with the western. Whereas in the west rising lands were eroded, carved into hilly or

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Map prepared in collaboration with Dr. T. W. Stanton.


UPPER CRETACEOUS
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
130°
110°
100°
90°
80°
70°

mountainous landscapes, and yet became more elevated, in the east the surface was a vast plain and remained a lowland.

The close of the Cretaceous was marked by a general ebb of the seas that had prevailed over continents, possibly because the ocean basins deepened. In central western North America the land was rising also, and the combined effect was to withdraw the waters of the strait to the Gulf on the south and to the Arctic on the north.

CENOZOIC HISTORY OF THE LARAMIE REGION, WYOMING[1]

ELIOT BLACKWELDER
University of Wisconsin, Madison, Wis.

The region described in this paper centers in the city of Laramie in southeastern Wyoming. It is situated in the eastern edge of the Rocky Mountain province. Much has been written about its stratigraphy and structure, but less of its physiographic features and their origin. The latter I purpose to describe and interpret here, with such help as is afforded by the contemporaneous deposits. Some of the questions which arise may be decided even now with reasonable confidence, but others require the further study which will be given them in later years. Even on these doubtful points suggestions may be of value to those who pursue the future work.

Bed-rock geology.—The fundamental rocks of the district are granites, gneisses, and schists of pre-Cambrian age. Upon their deeply eroded surface rests a thick succession of unaltered sedimentary rocks which range from Pennsylvanian to late Cretaceous. Although some unconformities divide this series, it appears nevertheless to be a unit, structurally. Under the plains the strata are nearly flat. In the mountains they have been arched in unison and are now found dipping away at various angles from the axes of the anticlines. From the physiographic point of view the sedimentary sequence may be divided into two parts: the Carboniferous limestone and the younger beds chiefly of Permian and Mesozoic age. The limestone is the most resistant terrane of the district and its outcrops are usually marked by "hog-back" ridges. The shales and weak sandstones of the other divisions are exposed in the lowlands bordering the mountains.

Upon the eroded edges of the tilted Mesozoic and older rocks lies a third group of strata—the Tertiary and Pleistocene sediments. They are nearly horizontal and largely unconsolidated.

[1] Published by permission of Director, U. S. Geological Survey.

Cretaceous sedimentation and orogeny.—If one may judge from the uniformity of the Cretaceous strata and the prevailing fineness of the materials of which they are composed, they were deposited upon a nearly level surface distant from any rugged highlands. Through much of the period this surface was beneath the sea, as

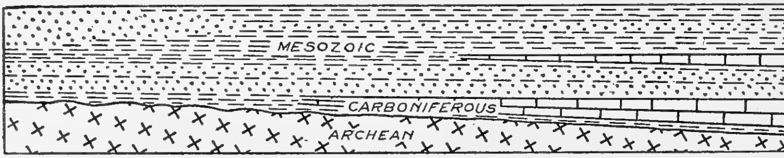


FIG. 1.—Probable condition of the Laramie district in late Cretaceous time.

shown by marine fossils; but toward the close it appears to have become a broad flat river-built plain[1] with marshes and lakes. It seems clear, then, that up to this time the Rocky Mountains were not in existence, and that the Mesozoic strata lay like a horizontal blanket over all of the Laramie district.

The events of the initial Rocky Mountain disturbance are not satisfactorily recorded in the Laramie district. It has long been known, however, that at or near the close of the Cretaceous period the flat-lying strata of the Rocky Mountain province were wrinkled into their present attitudes, and locally were broken by faults. A distinctive negative feature of the Laramie region is the absence of the volcanic activity which, in many parts of the West, was a conspicuous accompaniment of this great disturbance.

Neglecting for the moment the effects of denudation, it may be said that these movements resulted in the formation of a low broad arch on the site of the present Laramie range, and a more irregular uplift, with local faults facing eastward, where the Medicine Bow ranges now stand.

Eocene erosion.—An immediate result of the mountain-building epoch must have been a period of active erosion of the rising arches. There is no reason to doubt that this accompanied the growth of the folds and carved them into rugged highlands from the very beginning of the uplift; but it also continued long after the structure of the ranges

[1] The interpretation advocated by Chamberlin and Salisbury (*Geology*, 1904, No. III, p. 152) and others.

had been completed and static conditions reached. From the entire absence of exposures of Eocene sediments in southeast Wyoming, we may suspect that the chief activity of the region throughout the Eocene epoch was denudation. The abundance of pebbles of pre-Cambrian schists and granites in the basal gravel of the Oligocene series shows that the cover of stratified rocks had been entirely removed from the arches, and that the ancient rocks themselves were deeply eroded during the Eocene cycle. The folds were therefore truncated during Eocene time.[1]

Just what the final topographic result of this epoch of erosion was is now difficult to discern. There is some evidence, however, that it was not the complete planation of the district. Along the eastern border of the Laramie uplift the Oligocene deposits lie in valleys which had previously been cut through the limestone ridge. The intervening "hog-backs," which mark the outcrops of the Carboniferous limestone, stand 300–500 feet above these buried valleys. The relief just previous to the making of the Oligocene deposits must therefore have been at least as great in some parts of the district as that of the present.

On the other hand, the Oligocene deposits are notably fine and well stratified. They are not such formations as accumulate along the flanks of high mountains where streams have steep descents. From such facts as these it seems probable that by the close of the Eocene epoch the district in general was relatively low, but that the Laramie anticline was a hilly belt, while perhaps more rugged mountains were left farther west.

This uneven Eocene surface is preserved where it is still covered by the Oligocene strata, but over the rest of the area it seems to have been very largely destroyed by later cycles of erosion.

The Medicine Bow ranges west of the Laramie basin are essentially a maturely dissected plateau of schistose rocks with an average elevation of 10,000 feet. The plateau is topped by the rugged glaciated peaks locally called "the Snowy range," and by some lesser monadnocks. Farther east along the Laramie arch the nearly level

[1] Since this article went to press, my attention has been called by Mr. Bailey Willis to evidence indicating that the arches were partly uplifted in earlier Mesozoic times, and that the Paleozoic cover was removed from them before the Cretaceous sediments were laid down.

top of Pole Mountain, at an elevation of 9,000 feet, may correspond in both origin and age to the Medicine Bow plateau. It rises high above the remarkably even surface later to be described as the Sherman peneplain. In the absence of more satisfactory evidence, I can only suggest as a plausible hypothesis, that this Medicine Bow plateau surface and Pole Mountain are remnants of the one developed by the Eocene cycle of denudation. When neighboring regions have been examined with these problems in mind the hypothesis may be either verified or cast aside.

Mid-Tertiary sedimentation.—Reference has already been made to the Tertiary sediments which underlie the region east of the Sherman uplift. These consist largely of clays, soft sandstone, and conglomerate. As a rule the finer sediments are evenly stratified, and the colors are prevailingly light, being either white, gray, or yellow. The conglomerates are cross-bedded and locally indurated. It has been customary in the past to speak of these and similar deposits throughout the western mountain region as "lake beds," on the theory that fine stratified sediments could be deposited only in seas or in lake basins. More recently this origin has been called into question by Davis, Chamberlain, and others. It is now fairly well established that most of these Tertiary formations resemble those now being made by aggrading rivers, while some others bear a striking resemblance to eolian deposits. In the region under discussion it is highly probable that the Tertiary formations were deposited by streams in association with other terrestrial agencies, and the predominance of fine sediments indicates merely that the currents, whatever their nature, were of relatively weak transportive power.

The Oligocene beds resting on the eroded Eocene surface seem to imply that the erosive activities of the Eocene epoch were later subverted and gave way to aggradation. It is well, however, to bear in mind the alternative hypothesis that, without any marked change, a sheet of Piedmont alluvium which had been accumulating farther eastward during the Eocene epoch gradually spread westward as it was built higher and the highlands were reduced. In either case, the fact remains that the Eocene valleys were filled with clays and sands, and these sediments finally buried the lowland east of the Sherman uplift to a depth of several hundred feet. Embayments of this sheet

of alluvium extend westward up into the valleys in the Sherman highlands, thus burying the outcrops of the upturned Carboniferous rocks, as already described. Even the divides between these valleys were more or less covered by the same deposits, for at Granite Canyon Tertiary beds are found lying on the top of one of these divides.

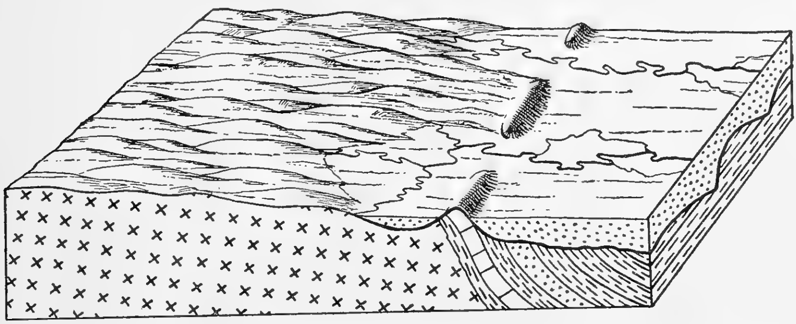


FIG. 2.—(Stereogram.) The Laramie uplift in the Oligocene epoch. The east flank partially buried by terrestrial deposits.

No trace of the middle Tertiary sediments has been found within the southern part of the Laramie basin. Just what the meaning of this fact may be is not now clear. While the Eocene surface (of which the Medicine Bow plateau is possibly a remnant) was being buried and thus preserved, east of the mountains, by the continued up-building of the Tertiary strata, corresponding denudation of the Sherman and Medicine Bow uplifts was probably in progress; but the record of it, if preserved, is too obscure to be read with any degree of confidence.

The exact age of the Tertiary sediments is a matter of considerable importance in working out the history of this region. According to Darton the lowest beds are the Chadron sands and the Brule clays, both of Oligocene age. These are followed by the conglomeratic Arikaree formation, which he assigns to early Miocene time. The close correlation of the Tertiary formations of the Great Plain is a matter of considerable difficulty, and perhaps the determinations thus far made should not be accepted too exactly. If, however, they are approximately right in this case, we may assign the epoch of

alluviation to the Oligocene and early Miocene times.[1] This also gives us a convenient datum point to which we may refer some of the later events of the district.

Later Tertiary peneplain.—One of the most striking peculiarities of the Sherman uplift is its monotonous and relatively even surface. No imposing range of mountains, like that of the Uinta arch, marks its site. Roads run in almost every direction; and the Union Pacific

FIG. 3.—Subdued crest of the Laramie uplift, near Tie Siding. Undissected Sherman peneplain.

Railroad crosses the divide, not through a deep pass, but across an open plateau. At the station of Sherman one may look for miles in almost any direction, and it is with difficulty that he realizes that his

[1] That this was not a time of constant conditions is indicated by the fact that the Arikaree is a coarse formation and lies unconformably on the finer sediments below. The significance of these facts has been commented on by Darton (*U. S. G. S. Professional Paper 32*, pp. 185, 186) and, as I am not in a position to add to his interpretation, they are passed over at this time.

viewpoint is 8,000 feet above sea-level, or as high as the summits of many of the rugged mountain ranges of the Northwest. When a closer examination is made, it is obvious to the geologist that the gently arched surface just described is in reality a plain of denudation, now more or less dissected. This surface passes with very little change across the outcrops of many different kinds of rocks. Schists, gneisses, porphyries, and gabbros are alike worn to a common level; and so slightly do they affect the details of the topography that surface forms are of doubtful value in mapping the outcrops of the different rock-formations. That the surface is a cut plain rather than a built plain is at once obvious, for outcrops of bed rock appear abundantly in it, although the majority of them are subdued and rounded, or even reduced to the level of the plain itself. In railroad cuts and in the open pits at Buford one may see that the granite and other rocks constitute all of the foundation, with scarcely any covering of soil or transported materials. The rocks are, however, deeply decayed, the granite being so soft that it is excavated with steam shovels to a depth sometimes exceeding 50 feet. In many exposures only the loose granitic gravel is to be seen, and by this alone the hasty observer might be misled. In these very exposures, however, one may often see quartz veins and small dikes, traversing the loose rubble right up to the grass-grown surface of the plateau. This shows that the material has not been disturbed. It is simply a thoroughly decayed mass of granite and other rocks.

It is, of course, not to be expected that this nearly level surface is a perfect plain. Here and there irregular knobs and piles of exfoliated bowlders rise above it, and a few hills or mountains of considerable size are scattered here and there over its surface. The highest of these are grouped in the Sherman Mountains, which have a maximum relief of nearly one thousand feet above the plain. These isolated elevations are doubtless monadnocks. Farther east, marking the outcrops of the hard Pennsylvanian limestone, there is a series of sharp hills or hog-backs which stand higher than the general surface of the Sherman peneplain. The coarse granite on the west and the soft sediments on the east are more easily eroded than the massive limestones.

The identification of the peneplain upon the Sherman uplift is a

comparatively easy matter, because of the complexity of the rock structure beneath. Elsewhere difficulties are introduced. The high plateaus between the Sherman arch and the city of Cheyenne are seemingly an easterly continuation of the peneplain, for their tops

FIG. 4.—Decayed granite cut by a basic dike. A feature of the Sherman peneplain surface.

are at the proper elevation and do not seem to correspond exactly with the structure of the underlying rocks. However, the fact that the beds from which they have been carved are horizontal makes it

difficult to prove that the plane surface is the result of planation rather than of structure.

That the Sherman peneplain in the typical locality is of later age than the mid-Tertiary formations is indicated by the fact that it passes directly across the embayments of Tertiary sediments along the east side of the arch. If the tops of the plateaus farther east are a part of the same plain, as seems probable, we have additional evidence in the fact that there also the Tertiary beds are truncated by this surface. There is, therefore, basis for the opinion that the age of this peneplain is late Tertiary, or more exactly that it has been made since the middle of the Miocene epoch. What connection the Sherman peneplain may have with the Eocene surface is very difficult to determine. It is probable that the Sherman plain truncates the older surface over the Sherman arch, while eastward the relation is reversed, and the Sherman plain lies high above the buried Eocene surface.

Passing to the east side of the Medicine Bow plateau, we again meet some features suggestive of the topography of the Laramie uplift. On the slopes of Jelm Mountain flat spurs are cut upon highly inclined schists at a level nearly 1,000 feet below the plateau surface. These seem to correspond roughly with the flat top of Red Mountain and, farther east, with the plateau surface of Boulder Ridge. If the Sherman pene-

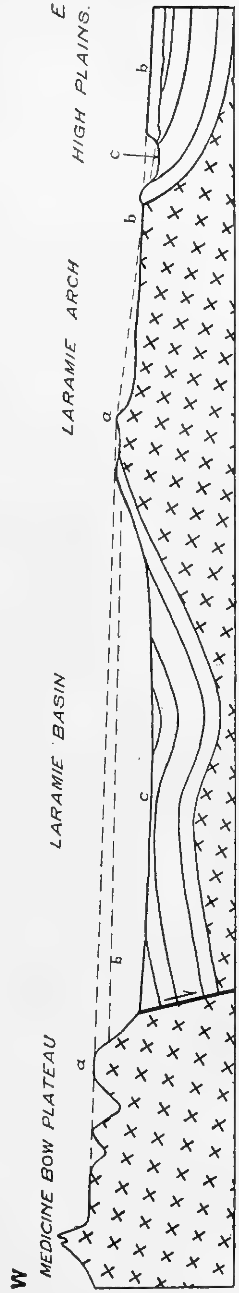


FIG. 5.—Section showing supposed relation of the Tertiary erosion surfaces to the present topography, in the latitude of Laramie. (*a*, Medicine Bow surface; *b*, Sherman surface; *c*, Leslie valleys.)

plain is represented in this part of the district these features may well be outliers of it. The topography on the west and south sides of the Laramie basin thus seems to correspond fairly well with that on the east, suggesting a common physiographic history for the several parts of the district.

In the Laramie basin itself I have not been able to recognize any remnants of the Sherman or older surfaces, and in explanation of this I suggest on a later page that the basin has been excavated in the Sherman plain.

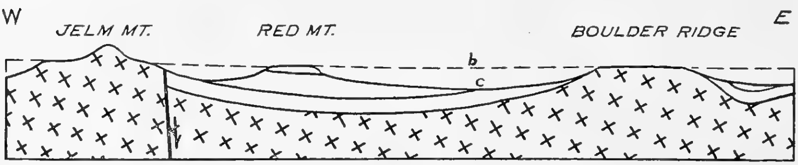


FIG. 6.—Section showing supposed relation of the Sherman surface to the present topography, near the south end of the Laramie syncline.

The Leslie cycle.—As described above, the Sherman peneplain is represented by a series of flat divides between the valleys which cross the Sherman uplift. A study of these valleys on the topographic map shows at once that their upper reaches are very different from the lower. On the eastern flank of the uplift the streams run in narrow canyons of considerable depth. Near their heads, however, the valleys are conspicuously open, broad, and flat-bottomed. The creeks meander considerably, and are bordered by broad meadows. These portions of the valleys are occupied by ranches, the meadows furnishing the hay for winter feed, while the cattle are pastured on the grassy divides between. The mining village of Leslie is situated in such a valley. Since there is no difference in the rocks, there can be little question but that the two divisions of these valleys represent two distinct cycles of erosion. The head of the valley is the older portion, while the canyon is the result of more recent rejuvenation.

It has been suggested that the Leslie valleys are not later in age than the Sherman peneplain, but that they are merely shallow open valleys in a very advanced age, and that the flat spurs between them are the subdued divides of the same cycle. I find it hard to reconcile

this idea with the existence of flat plateaus east of the Sherman uplift. Their sides are relatively steep, and the valleys ascribed to the Leslie cycle are rather sharply sunk beneath them. Such a hypothesis should have consideration in future study of the district, but the weight of evidence seems to me favorable to the view that the Leslie valleys have actually been excavated in a surface which was even less rough—the Sherman peneplain. If the latter hypothesis is correct, then we have evidence of a cycle of erosion initiated by the rejuvenation of the streams after the completion of the Sherman peneplain.

This change in the activity of the streams may have been produced by actual uplift, or by a climatic variation. The sediments corre-

FIG. 7.—Sketch (from a photograph) of a flat-bottomed open valley (Leslie stage) near the crest of the Laramie range.

sponding to these erosion cycles have not been recognized, and it is therefore difficult to get any data bearing on the climatic changes. Uplifts are known to have occurred at intervals during the Tertiary and Quaternary periods, and the occurrence of one in this district is not improbable.

East of the uplift again we find broad flat-bottomed valleys sunk beneath the plateau surface which has been interpreted as the Sherman plain, but themselves trenched by canyons which are obviously younger. The largest of these broad depressions has been excavated parallel to the Sherman arch east of the limestone hog-backs, apparently because the soft Brule clay is exposed there. In the building of the

Colorado and Southern Railroad advantage has been taken of this depression. The bottoms of these saddles now lie from one to three hundred feet above the present creeks. They have no very clear relation to the present stream courses. While it has not been possible to trace these valleys directly into the open head-water courses which represent the Leslie cycle in the type locality, both have the same general relation to the upper or Sherman surface and to the modern canyons.

As stated above, the Laramie basin seems best explained as a depression excavated in the Sherman peneplain. In this connection I have considered the possibility that the basin is a modified downwarp between two upwarps or horsts; but this view seems to necessitate a series of remarkable coincidences by which several small upwarps affected only the somewhat irregular areas of resistant rocks and not the softer strata now exposed in the basin. On the other hand the present conditions are such as would be produced by the deeper excavation of a plain in which both hard and soft rocks are exposed. Rejuvenation readily explains this excavation. The soft Mesozoic beds were rapidly cleaned out of the Laramie syncline while the hard Paleozoic limestones and pre-Cambrian rocks were left in relief. If running water was the agent of denudation, the downward cutting was checked at the level of stream-grade and then planation at a slowly subsiding level ensued. If wind has been the dominating agent, then these nice adjustments are unnecessary. There is clear evidence that both processes are in operation, and since the Laramie river is perennial the water erosion probably dominates.

On first consideration one may experience some difficulty in explaining on this hypothesis the steep slope by which the Laramie basin is separated from the mountainous region on the west. Sheep Mountain and Jelm Mountain rise abruptly out of the plain. Both are partially flanked by faults, but the faults appear to be of ancient date (Cretaceous-Eocene) like those elsewhere in the district, for they have no topographic expression where they run out into the sedimentary rocks. From this fact it appears improbable that they are recent scarps. The faults have brought the soft Cretaceous shales squarely in contact with the much harder pre-Cambrian rocks—in the case of Sheep Mountain, a firm granite. The weaker strata

must have been rapidly stripped from the granite wall, while only insignificant ravines were being cut in the face of that wall. Furthermore, where there are no faults, as around the hills southeast of Jelm Mountain, the pre-Cambrian rocks rise equally abruptly out of soft sandstones and shales. The massive limestone formation, which on the east side of the Sherman arch gives the sharp hog-back ridges, is replaced in the space of less than forty miles by an entirely different series, in which there are no very resistant members. The absence of the hog-backs is thus explained.

The highest surfaces of the broad Laramie plain are certain mesas, well represented by the rim of the Great Hollow. The tops of these mesas descend very gently from an elevation of 500 feet above the river, near the mountains, to about 100 feet above it, near the city of Laramie. At first glance they might be mistaken for outliers carved from a plain of alluvial aggradation, for the surface is very even and rock exposures are rarely visible at any distance. When carefully examined, however, it is found that inclined strata, chiefly of Mesozoic age, are exposed in many places throughout the plain; and, although they are covered by a layer of gravel, sand, and loam, this covering is never deep. Near the mountains on the west the sheet of alluvium, only a few feet in thickness, consists of coarse gravel, which is gradually replaced farther outward and down-stream by finer and finer materials. The deposits are such as are left by shifting streams, graded only for coarse material, which slowly reduce the level of their basins, while at the same time they widen them much more rapidly. The Laramie basin then is not a filled basin, but a cut plain; and the Laramie River is at present engaged in continuing the planation at a slightly lower level.

In the Laramie basin one finds no distinction between open valley heads and canyons below. All is open. I interpret this to mean that the Leslie cycle still reigns in that part of the district, the wave of rejuvenation, whatever its cause, not having worked up the Laramie River far enough to be felt within the basin.

The Hecla cycle of canyon-making.—Reference has already been made to the canyons which are sunk beneath the broad valleys of the Leslie cycle. As the open valleys in the Sherman uplift are traced eastward, they become narrower and are walled in by pre-

cipitous cliffs. The gradients of the streams are so steepened that bowldery rapids replace the grass-grown channels characteristic of the Leslie stage. Some of these canyons are three to four hundred feet deep and wholly impassable except for one on foot. Although cut chiefly in granite, they are apt to be narrowest where they pass through the upturned Carboniferous limestone. As would be expected, these younger valleys have been considerably widened in the soft Tertiary strata farther east. There again flat bottoms have been developed, and ranches are scattered along the streams. The sides of the valleys are steep, however, and tributaries coming in from the abandoned upper reaches, which I have interpreted as belonging to the Leslie cycle, descend the slopes abruptly.

In the Laramie basin we find no trace of the canyon cycle. I have suggested that the backward cutting of the canyons from the lower course of the Laramie River has not yet progressed as far as the Laramie basin. If this view is correct, the Laramie basin is still in the Leslie cycle, and its rivers have suffered no marked disturbance for a peiod of time sufficiently long to enable them to plane off broad flat valleys. Rejuvenation such as is indicated by the canyons has ordinarily been ascribed to diastrophic disturbances. More recently Johnson[1], Davis,[2] and others have emphasized the competence of climatic changes to produce the same results. In this particular case the cause has not been worked out. It can probably be done best by a broad study of the whole of the Great Plains and eastern Rocky Mountain region.

As to the age of the canyon cycle some inferences may be made. Assuming that the Sherman peneplain is post-Miocene, a considerable length of time must be allowed in addition for the excavation of the open Leslie valleys, unless these are to be correlated with the Sherman cycle itself. On this line of estimation the canyons should be no older than Pliocene. Approached from the other direction, it may be said that the canyons represent a very youthful stage of the present cycle of erosion. In other parts of the West it is known that valleys of comparable development have been made since the early part of the

[1] W. D. Johnson, "The High Plains and Their Utilization," *U. S. G. S. Ann. Rep.*, XXI, Part 4, pp. 630, 631.

[2] W. M. Davis, "Explorations in Turkestan," *Carnegie Institution Publication No. 26*, pp. 203–6.

Pleistocene period. It is probably safe then to consider these canyons as of Pleistocene age.

Absence of glaciation.—The Laramie Range was too low to generate glaciers during the Quaternary period. The evidence of this is both positive and negative. The topography is entirely such as is produced by the action of running water and wind, and the thin residual soils have been in no wise disturbed. On the other hand, there is an entire lack of glacial drift in the district. The same is true of the greater part of the Medicine Bow plateau, although the highest range of these mountains—locally known as the "Snowy Range"—shows, even at a distance of forty miles, the characteristic sharp peaks and cirques produced by Alpine glaciers, and some of the tongues of ice ran far down their individual valleys. Judging from the Bighorn Range farther north, an elevation of more than ten thousand feet would have been necessary to induce glaciation in this latitude and climate.

Modification of the topography by wind.—Here, as in most parts of the dry West, the wind has been an agent of great importance. Mushroom monuments and other wind-carved forms are widely distributed. The many shallow hollows—some containing ponds—which are characteristic of the region, seem to be explainable only as the work of the wind. They appear in all sizes, from little saucer-like depressions to such features as the "Big Hollow" west of Laramie which is nine miles long and 150 feet deep. They are independent both of the kind of rock and the elevation, being found as well in the granite on the Sherman plateau as in the present flood plain of the Laramie River. These land forms, the stony flats strewn with polished bits of flint and honeycombed limestone, and many other significant things, testify to the efficiency of wind erosion in the Laramie region. The depositional phase of wind-work has not, however, impressed itself perceptibly on the topography. The abraded material has been largely exported.

Summary and conclusions.—Briefly stated, the more important points in the later history of the Laramie region, as interpreted in this paper, are these:

1. The district was completely buried beneath the horizontal beds of Cretaceous sediments.

2. About the close of that period the beds were moderately folded and locally faulted.

3. During the resulting cycle of erosion, the arches and scarps were beveled off and a moderately low hilly surface was produced.

4. Through terrestrial sedimentation in the Oligocene and Miocene epochs the Eocene surface was partially buried, although it probably remained exposed in the mountains.

5. After this, probably in Pliocene times, much of the region was reduced to a peneplain on which some notable monadnocks remained standing.

6. This was followed by rejuvenation, and the resulting cycle of erosion was long enough to permit the cutting of wide flat valleys in the arches and the excavation of the Laramie basin.

7. The most recent episode is a later rejuvenation which has caused new canyons to be cut east of the Laramie divide but not as yet in the plain west of it.

8. The region has not been glaciated, but its surface has been modified in detail and perhaps in gross by wind carving.

CHEMICAL COMPOSITION AS A CRITERION IN IDENTIFYING METAMORPHOSED SEDIMENTS[1]

EDSON S. BASTIN

In the literature dealing with metamorphism there is repeated reference to the applicability of chemical analyses in the differentiation of schists and gneisses of sedimentary origin from those of igneous origin, and the usefulness of this method has been generally recognized. There are, however, remarkably few definite statements in regard to the exact character or magnitude of the chemical differences to be expected in rocks of these diverse origins. The compilations of Washington have within recent years made available to the geologist practically all of the superior analyses of igneous rocks published prior to 1903, and the present study was attempted in the belief that these tables furnished a basis for statistical comparisons which would lead to more definite conceptions concerning the chemical differences between igneous and meta-sedimentary rocks. In making these comparisons the writer had to make his own compilations of analyses of the meta-sedimentary rocks, and while the results are believed to be sufficiently accurate for the purposes of this paper, a general compilation of analyses of sedimentary and meta-sedimentary rocks is highly desirable and would prove of immense service to geologists in general and to students of metamorphism in particular.

The literature of this subject is not extensive and may be summarized as follows:

The subject has been treated more fully by Rosenbusch[2] than by any other writer. He points out[3] that the proportions of the con-

[1] Published with the permission of the Director of the United States Geological Survey.

[2] H. Rosenbusch, "Zur Auffassung der chemischen Natur des Grundgebirges," *Tschermak's Mineralogische und Petrographische Mittheilungen*, Neue Folge, Band XII, 1891.

[3] *Ibid.*, p. 51: " . . . . die Bestandtheile eines Eruptivmagmas und also eines Eruptivgesteines nicht anders als gesetzmässig sein können, während in einem mechanischen Gemenge—und das sind doch die ursprünglichen Sedimente—an und für sich eine Gesetzmässigkeit in den relativen Mengen der Bestandtheile nicht vorhanden sein muss."

stituents in an eruptive magma and also in an eruptive rock are governed by definite laws, whereas in mechanical mixtures such as the sedimentary rocks, no such definite relationships need exist. Further he says,[1] that if we find in a crystalline schist such proportions between the chemical constituents as exist in no eruptive rock, we may conclude that the same cannot have been formed from an eruptive rock through any sort of dynamic metamorphism. If on the contrary the chemical makeup of a crystalline schist is the same as that of a certain eruptive rock, we must concede that the former *may* have been formed through dynamic metamorphism from the latter, not, however, that it *must* have been so formed, since certain clay schists can unquestionably possess the composition of granites.

He further expresses the opinion that dynamic metamorphism does not greatly alter the chemical character of the rocks concerned,[2] and in support of this view cites (1) the close chemical resemblance of certain types among the unaltered rocks to certain of the dynamically metamorphosed rocks; of diorite schists to diorites; of certain amphibole schists to gabbros, etc.; (2) the variety of very distinct rock types found in a regionally metamorphosed province and the usual sharp demarkation between them, gradation zones (*Mischungszonen*) being for the most part absent.

He points out[3] that certain gneisses are differentiated from igneous rocks by their high alumina content, the alumina being much in excess of the 1:1 ratio in which it is commonly combined with the CaO, K_2O, and Na_2O of the rock. Other gneisses though low in alumina reveal their sedimentary origin in an iron content notably higher than that of any igneous rocks carrying similar percentages of lime, magnesia, and alkalies.

Grubenmann in *Die kristallinen Schiefer*[4] remarks as follows:

Sedimentary rocks in their chemical makeup plainly lack certain regular relationships which within certain limits are so characteristic of igneous rocks. This condition is not destroyed in the metamorphism to a crystalline schist but

[1] *Op. cit.*, pp. 51, 52.

[2] *Ibid.*, p. 52: "die Dynamometamorphose den chemischen Charakter der ihr unterliegenden Gesteine nicht wesentlich ändert."

[3] *Ibid.*, pp. 54, 55.

[4] Vol. I, p. 12 (translation by the writer).

becomes even more clearly defined and hence can be disclosed by the chemical analysis. Yet even this (chemical) method does not always give us the desired result, since there are rocks, such as arkoses, shaly sandstones, and sandy shales, which approach igneous rocks very closely in their chemical composition.

In his chapter on the recognition of schists of igneous origin, he adds:[1]

. . . . as already mentioned, the chemical makeup of igneous rocks shows certain characteristic features in the proportions in which the constituent oxides are mixed. . . . . Moreover these features persist throughout the metamorphism so that the chemical analysis furnishes a second and usually a safer means of recognizing the igneous origin of a schist.

Van Hise in his *Treatise on Metamorphism*[2] says:

A third criterion of great importance in the discrimination of metamorphosed sedimentary and igneous rocks is chemical composition. It has been shown that the materials for sedimentary rocks are sorted, that in general there is depletion in certain of the elements as compared with the igneous rocks, and that the proportions of the elements in the sedimentary rocks are therefore different from those in the igneous rocks. Furthermore, it has been shown that in the zone of anamorphism the chemical composition of rocks is not greatly changed during the process of metamorphism, and it has already been seen that this is the only zone in which metamorphism is likely to result in the confusion of the two classes of rocks. Therefore the metamorphosed sedimentary and igneous rocks which are likely to be confused have the compositions which are characteristic of their class: the metamorphosed sedimentary rocks, with minor modifications, have the chemical composition of muds, grits, sandstones, etc.; the metamorphosed igneous rocks have the compositions of granites, diorites, etc. For both sedimentary and igneous rocks there are wide variations in chemical composition, but in general the proportions of the elements are markedly different, in the two classes, as may be seen by comparison of the composition of the metamorphosed sedimentary rocks and that of the metamorphosed igneous rocks. The criterion has great value in some cases where the criterion of banding fails, for instance, in discriminating between metamorphosed sedimentary rocks and metamorphosed tuffs. The metamorphosed sediments have their characteristic compositions, while the metamorphosed tuffs, notwithstanding the fact that they may show banding, and thus closely resemble metamorphosed sediments, have the composition of igneous rocks.

In discussing the composition of muds, he says:[3]

. . . . muds are likely to be deficient in the more readily soluble compounds. Of these the alkalies stand first, and of the alkalies sodium is more largely dissolved,

[1] *Ibid.*, p. 13.

[2] Monograph XLVII, U. S. Geol. Survey, pp. 914, 915.

[3] *Ibid.*, p. 889.

since a large proportion of sodium in the original igneous rocks occurs in minerals which are more readily decomposed than the minerals which bear potassium—that is, sodium occurs largely in the nephelites, sodalites, and basic feldspars, which are readily soluble; whereas the great sources of potassium are orthoclase and microcline, difficultly decomposable minerals. The materials are also apt to be depleted in calcium and magnesium, since the alkaline earths are so readily soluble. The depletion in calcium usually has gone farther than the depletion in magnesium, since in the belt of weathering much of the magnesia is retained in the serpentines and talcs. The material may or may not be depleted in iron. While aluminum and silica also have been dissolved in the belt of weathering, the solution of these substances is less rapid than of the others, and thus there is usually an increase in the relative amounts of these elements.

In discussing the analysis of a slate from the Menominee district, Mr. J. Morgan Clements says:[1]

That which is most striking about the analysis is the relative proportion of the alkaline earths, lime and magnesia, the latter being present in the greater quantity. As a rule, in all of the igneous rocks (and to the igneous rocks all clay slates owe their ultimate origin), except in the non-feldspathic ultrabasic ones, the reverse condition exists, namely, the magnesia is subordinate in quantity to the lime.

Dr. F. D. Adams[2] remarks as follows:

When any granite or granitic rock is for long periods exposed to a process of gradual decay there finally results a mass of kaolin, often mixed with more or less chloritic material, holding the quartz of the original rocks as grains scattered thickly through it. When sorted by the action of moving water it gives rise to beds of sand and clay. The chemical processes at work during this process of decay consist in the more or less complete removal of the alkalies of the feldspar, and of the decomposition of the iron-magnesia constituents with the loss of a large proportion of the lime as compared with the magnesia.

On comparing the analyses of a series of granites and those of a series of slates, as for instance those given in Roth's *Gesteins Analysen*, the latter are seen to be on an average considerably higher in aluminum and much lower in alkalies, while at the same time they are lower in silica which has been separated both as sand and in combination with the alkalies which have gone into solution, and in most cases contain more magnesia than lime instead of more lime than magnesia as is usual in the granites.

The characteristics of foliated rocks of sedimentary origin which have been considered useful in distinguishing them from foliated rocks of igneous origin may be summarized as follows:

[1] Monograph XXXVI, U. S. Geol. Survey, pp. 59, 60.

[2] F. D. Adams, "Contributions to Our Knowledge of the Laurentian," *Amer. Jour. Sci.*, 3d series, Vol. L, pp. 64, 65.

I. The presence of silica in certain schists and gneisses in larger proportions than in most igneous rocks.

II. The presence in many of alumina in amounts considerably in excess of that necessary to satisfy the ratio of 1:1 in which it is combined with lime and the alkalies in the common rock-forming silicates.

III. Dominance of magnesia over lime.

IV. Dominance of potash over soda.

In the following pages the writer purposes to show that foliated structures may be developed in many rocks without important changes in chemical composition, and proposes to consider in detail the value of each of the above criteria. Before discussing the criteria further it will be well to differentiate the types of foliated rocks and determine to which ones they can be appropriately applied. The foliated rocks may be classified as follows:

FOLIATES[1]

I. *Primary foliates* (flow-foliates or ortho-foliates).—Here belong the flow-gneisses and all igneous rocks whose foliated structure is original and is due to differential movements in the igneous magma before complete solidification.

II. *Secondary foliates* (metamorphic-foliates or para-foliates).—Rocks whose foliated structure has been induced by metamorphism subsequent to their complete consolidation.

- 1) *Meta-igneous foliates:*
  - *a*) Meta-plutonic foliates.
  - *b*) Meta-volcanic foliates.
- 2) *Meta-sedimentary foliates:*
  - *a*) Siliceous foliates.
    Quartzitic schists and other metamorphic derivatives of highly quartzose sediments.
  - *b*) Calcareous foliates.
    Banded marbles and other metamorphic derivatives of highly calcareous sediments.
  - *c*) Pelitic foliates.
    Slates, phyllites, argillaceous schists, and other metamorphic derivatives of argillaceous sediments.

[1] The term "foliates" is here used as a convenient comprehensive term to include all rocks showing foliated structures other than bedding planes. Its use in a discussion of this kind saves frequent repetitions of the two terms, schists and gneisses, and avoids any postulate as to the primary or secondary character of the foliated structure.

d) Frangitic[1] foliates.

Arkose-schists, graywacke-schists, and other metamorphic derivatives of sediments produced by disintegration of igneous rocks without much decomposition or mechanical sorting of the constituents.

III. *Foliates in which the parallel structure is in part primary and in part secondary.*

1) *Injection foliates:*

Here belong the injection gneisses.

The primary foliates whose foliated structure is due to differential movements within an igneous magma before complete solidification have the composition of massive igneous rocks and may therefore be excluded from this discussion. The foliates of the third class, typified by the injection gneisses, are also excluded for obvious reasons. The secondary foliates are therefore the only ones whose chemical characters we need discuss. The igneous and sedimentary types will be considered in order.

THE META-IGNEOUS FOLIATES

The study of chemical characteristics by the method of averaging a large number of analyses, adopted for the meta-sedimentary foliates, is not applicable to the meta-igneous group because of the great variety of rocks represented and the relative scarcity of analytical data. It is necessary to restrict ourselves to the consideration of what appear to be representative cases and to comparisons between closely related rock groups.

In Dr. Watson's admirable report on *The Granites and Gneisses of Georgia*[2] he gives a large number of analyses of the normal granites and the metamorphic granite-gneisses of the state. Many of the gneisses are highly contorted and thin-banded, and under the microscope show evidence of dynamic metamorphism in the presence of undulatory extinction, peripheral granulation of the mineral grains, fractures traversing the larger grains of quartz and feldspar, and frequent partial or complete recrystallization. Mineralogically they

[1] The term "frangite" (from the Latin *frango*, "to break up") and its adjective "frangitic" is proposed as a comprehensive term for all sedimentary rocks formed from the disintegration of igneous rocks without extensive decomposition or mechanical sorting. It includes unconsolidated as well as cemented and dynamically metamorphosed representatives. It includes arkoses, graywackes, grits, graywacke-schists, and gneisses, etc.

[2] Thos. L. Watson, *Bull. 9–A*, Geological Survey of Georgia.

are almost identical with the normal granites. To quote Dr. Watson:[1]

. . . . the granite-gneisses differ from the more massive rock phases (granite) simply in the marked banded or foliated structure. These are secondary structures induced by long-continued and profound dynamo-metamorphism, acting on an originally massive rock, similar, in mineralogical and chemical compositions, to the existing massive granitic areas studied. . . . . The granite-gneisses represent unquestionable foliated phases of the massive granite similar to the present areas but of an earlier intrusion.

The granite-gneisses are entirely free from staurolite, andulusite, cordierite, kyanite, and similar minerals so characteristic of meta-sedimentary foliates.

In order to compare the metamorphosed and unmetamorphosed granitic rocks, the writer computed their position in the quantitative system of classification.[2] The granites were so similar in composition that their analyses were averaged and only the systematic position of the average computed. The results may be tabulated as follows:

GRANITES AND GRANITE-GNEISSES OF GEORGIA

		Class	Sub-Class	Order	Rang	Sub-Rang	Name
Normal granites	Average of 21 analyses	I	I	4	2	3	Toscanose
Porphyritic granites	Average of 10 analyses	I	I	4	2	3	Toscanose
Biotite-granite gneiss	4 analyses, separately computed	I	I	4	2	3	Toscanose
	2 analyses, separately computed	I	I	4	2	3–4	Between Toscanose and Lassenose
	3 analyses, separately computed	I	I	4	1	3	Liparose

It will be seen therefore that the granite-gneisses possess the composition of igneous rocks and are almost identical with the normal

[1] *Ibid.*, p. 263.

[2] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks*, 1903.

granites in composition. In Washington's tables[1] there are 141 representatives of the sub-rang Toscanose, 85 of Lassenose, and 103 of Liparose. They are mainly granites, rhyolites, and related rocks.

If we examine the individual analyses in respect to the proportions between MgO and CaO and between K_2O and Na_2O, we find added evidence of similarity.

	MgO>CaO	$K_2O>Na_2O$
In the normal and porphyritic granites	0 out of 39 analyses	22 out of 35 analyses
In the granite-gneisses	0 out of 10 analyses	7 out of 10 analyses

The granite-gneisses of this region therefore possess all the chemical characteristics of certain very common types of igneous rocks.

A large number of granites and granite-gneisses of Sweden have been described by Holmquist[2] in his "Studien über die Granite von Schweden." Many of these have been affected by dynamic metamorphism and show strongly developed parallel structure. Under the microscope they either exhibit well-defined kataclastic structure

METAMORPHOSED GRANITES OF SWEDEN

No. of Analyses	Holmquist's Numbers	Class	Sub-Class	Order	Rang	Sub-Rang	Name	Number of Representatives in Washington's Tables
2	103, 116	I	I	3	2	3	Tehamose	39
4	21, 120, 123, 134	I	I	4	1	3	Liparose	103
5	97, 117, 121, 122, 131	I	I	4	2	3	Toscanose	141
3	19, 20, 104	I	I	4	2	4	Lassenose	85
3	127, 135, 136	I	I	4	3	3	Amiatose	23
1	137	I	I	4	3	4	Yellowstonose	62
2	100, 124	II	I	4	2	3	Adamellose	25
1	25	II	I	4	2	4	Dacose	26
1	130	II	I	4	3	3	Harzose	31
1	22	II	I	4	3	4	Tonalose	124
3	101–125, 126	II	I	5	2	4	Akerose	44
1	102	II	I	5	3	4	Andose	128

[1] H. S. Washington, "Chemical Analysis of Igneous Rocks," *Professional Papers Nos. 14 and 28*, U. S. Geol. Survey, 1903 and 1904.

[2] Holmquist, *Bull. Geol. Institution*, University of Upsala, Vol. VII, pp. 77–269 (1904–5).

or else have suffered complete recrystallization. The position in the quantitative system of 27 of these metamorphosed granitic rocks was computed, and they were found without exception to fall in subrangs represented by numerous examples among massive igneous rocks. Their classification is as appears in the preceding table.

A comparison of the magnesia-lime ratios and alkali ratio in these granite-gneisses with those in the granites gave the following results:

	$MgO > CaO$	$K_2O > Na_2O$
In the unmetamorphosed granites...	1 out of 105 analyses	82 out of 105 analyses
In the metamorphosed granites.....	1 out of 27 analyses	14 out of 27 analyses

None of the metamorphosed granites show alumina in excess of the amounts common in many massive igneous rocks. Corundum is present in the norm of 8 out of the 27 metamorphosed rocks, but is never in excess of 2 per cent. From their chemical composition alone, therefore, it would be impossible to distinguish these 27 rocks from typical massive igneous varieties.

Certain rocks described by Teall[1] as early as 1885 afford an example of the dynamic metamorphism of a basic rock without notable changes in chemical composition. Two basic dikes traversing the more acid gneisses of Sutherlandshire, Scotland, are in part massive and in part highly schistose, the schistose portions being so distributed as to show that they were not produced by flowing movements in the dike before complete solidification, but are the result of regional metamorphism. Upon microscopic examination the massive phase is found to have the mineral composition and ophitic texture of a typical diabase, while the schistose phase is a hornblende schist devoid of kataclastic structures but with a perfect parallel structure, which is plainly the result of complete recrystallization. The principal mineral changes accompanying the development of the schistose structure are the replacement of augite by hornblende and the appearance of some free quartz in the schist. The chemical composition of the two rocks, as shown in analyses I and II, p. 454, is almost identical.

[1] J. J. H. Teall, *Quart. Jour. Geol. Soc.*, London, Vol. XLI, pp. 133–45 (1885).

	I Diabase		II Hornblende Schist	
	Per cent.	Mol. Prop.	Per cent.	Mol. Prop.
SiO_2	47.45	.791	49.78	.830
Al_2O_3	14.83	.145	13.13	.128
Fe_2O_3	2.47	.016	4.35	.027
FeO	14.71	.204	11.71	.163
MgO	5.00	.125	5.40	.135
CaO	8.87	.158	8.92	.159
Na_2O	2.97	.048	2.39	.039
K_2O	0.99	.011	1.05	.011
H_2O	1.00	....	1.14	....
TiO_2	1.47	.019	2.22	.028
CO_2	0.36	....	0.10	....
MnO	.....	....	0.27	.004
Totals	100.12	....	100.46	....

Norm of I				Norm of II		
			Quartz	2.76		
Salic	55.18	6.12	Orthoclase	6.12	51.00	Salic
		25.15	Albite	20.44		
		23.91	Anorthite	21.68		
		2.89	Ilmenite	4.26		
		3.71	Magnetite	6.26		
Femic	43.69	16.89	Diopside	18.68	48.20	Femic
		2.38	Hypersthene	19.00		
		17.82	Olivine			

Both rocks fall in class III, order 5, rang 3, and sub-rang 4, Camptonose.[1]

It will be seen therefore that, in spite of complete recrystallization, of complete change in texture, and of notable change in mineral composition, the chemical makeup of the rock has suffered little change.

A few other examples similar to those cited above are available in geologic literature and might be quoted if space permitted. The mass of chemical data, however, bearing on the metamorphism of igneous rock is regrettably small and the field is one of the most promising for geologic investigation.

In the opinion of the writer the data cited above show that in many cases perfect parallel structures have been developed in igneous

[1] Two changes are worthy of note in passing: first, the appearance of quartz both in the norm and the mode of the schist, and second, the change of some of the iron from the ferrous to the ferric state.

rocks without important changes in chemical composition. It lends support to the view expressed by Rosenbusch that most foliated rocks of igneous origin have not suffered any great chemical changes during dynamic metamorphism. It does *not* prove, however, that important chemical changes may not take place in *some* igneous rocks as a result of dynamic metamorphism.

THE META-SEDIMENTARY FOLIATES

Among the foliated rocks of meta-sedimentary origin the siliceous foliates may usually be recognized without detailed chemical studies from their highly quartzose character. Being more resistant than most other sediments to mass deformation they are also more likely to preserve during metamorphism traces of bedding and other original structures. It is seldom therefore that chemical data need be appealed to for the recognition of sediments of this type. The calcareous foliates also are usually recognized readily from their high carbonate content without recourse to refined chemical study.

It is evident, on the other hand, that the frangitic foliates, rocks like the arkose and graywacke-schists, which are the result of the disintegration of igneous rocks without much decomposition or mechanical sorting, will closely resemble their parent igneous rocks chemically, and that in such cases chemical criteria have little or no value for determining genesis. It is only in the recognition of the remaining division, the pelitic foliates, that chemical criteria are particularly useful, and it is here that they have been most frequently appealed to. It should be remembered, however, that the four types of sediments mentioned above are not sharply delimited but pass into each other through every conceivable gradation. It is not possible therefore to define the exact limits of usefulness of chemical criteria, though the major limitations outlined are believed to be essentially correct.

The chemical characteristics of the metamorphosed pelitic sediments can only be adequately studied by comparing a considerable number of analyses of slates, phyllites, and schists.

No. I below represents the average of 79 slate and phyllite analyses, 36 being from the United States and Canada and 43 from Europe. Only those of undoubted sedimentary origin and unaffected by contact

metamorphism were used. The majority are roofing slates. In the second column the averages are recomputed on the water-free basis. No. II represents the average of the analyses of 30 pelite schists and gneisses, mostly European, though a few from the United States and Canada were used. Only those definitely stated to be of sedimentary origin, or whose mineral character or geologic occurrence clearly showed that such was the case, were included. Schists affected by

I. SLATES AND PHYLLITES

	No. of Determinations	Averages of Analyses		Averages Corrected for Total Water	
		Percentage Weights	Mol. Prop	Percentage Weights	Mol. Prop.
SiO_2	79	60.49	1.008	62.97	1.049
Al_2O_3	79	17.56	0.172	18.28	0.179
Fe_2O_3	48	2.74	0.017	2.85	0.018
FeO	48	4.61	0.064	4.79	0.067
MgO	79	2.51	0.063	2.61	0.065
CaO	79	1.26	0.023	1.31	0.023
K_2O	74	3.31	0.035	3.44	0.036
Na_2O	74	1.32	0.021	1.37	0.022
TiO_2	46	0.73	0.009	0.76	0.010
CO_2	35	1.11	0.025	1.16	0.026
H_2O+	28	3.61	0.201	....	.....
H_2O-	28	0.31	0.018	....	.....
Total	....	99.56	.....	99.54	.....

II. PELITE SCHISTS AND GNEISSES

	No. of Determinations	Averages of Analyses		Averages Corrected for Total Water	
		Percentage Weights	Mol. Prop.	Percentage Weights	Mol. Prop.
SiO_2	30	65.46	1.091	66.67	1.113
Al_2O_3	29	16.32	0.160	16.64	0.163
Fe_2O_3	22	4.04	0.025	4.12	0.026
FeO	22	2.71	0.038	2.76	0.038
MgO	30	2.42	0.060	2.47	0.062
CaO	30	1.50	0.027	1.53	0.027
K_2O	30	3.40	0.036	3.47	0.037
Na_2O	30	1.89	0.031	1.93	0.031
TiO_2	24	0.89	0.011	0.91	0.011
CO_2	..	none	.....	....	.....
H_2O+	9	1.87	0.103	....	.....
H_2O-	9	0.09	0.006	....	.....
Total	..	100.59	.....	100.59	.....

contact metamorphism were also ruled out as far as possible. In the supplementary column the averages are recomputed to the moisture-free basis. The close relationship between the slate and schist averages is at once apparent. A notable feature of both is the dominance of MgO over CaO and of K_2O over Na_2O. It is noteworthy

	Sub-Class	Order	Rang	Sub-Rang	Remarks
Class I. Persalane	I	2	1	3	2 representatives of this sub-rang in W. T.;* 1 is schistose and not fresh.
	I	2	4	5	No representative of this rang in W. T.
	I	3	2	3	Tahamose; 29 representatives of this sub-rang in W. T.
	I	3	2	4	Alsbachose; 17 representatives of this sub-rang in W. T.
	I	3	3	2	8 representatives of this sub-rang in W. T.
	I	3	3	4	6 representatives of this sub-rang in W. T.
	I	3	4	2	2 representatives of this rang and 1 of this sub-rang in W. T.
	I	3	4	4	No representative of this sub-rang in W. T. and only 2 of this rang.
	I	3	4	4	
	I	4	2	3	Toscanose; 122 representatives of this rang in W. T.
	I	4	2	3	
	II	3	2	2	Only 5 representatives of this sub-class and 1 of this sub-rang in W. T.

* W. T.=abbreviation for Washington, "Tables of Chemical Analyses of Igneous Rocks," *Professional Paper No. 14*, U. S. Geol. Survey, 1903.

	Sub-Class	Order	Rang	Sub-Rang	Remarks
Class II. Dosalane	I	2			No representative of this order in W. T.
	I	2			
	I	3	2	2	1 representative of this sub-rang in W. T.
	I	3	2	3	2 representatives of this sub-rang in W. T.
	I	4	1	2	No representative of this sub-rang in W. T.
	I	4	1	2	
	I	4	2	3	Adamellose; 21 representatives of this sub-rang in W. T.
	I	4	2	3	
	I	4	2	3	
	I	4	2	3	
	I	4	2	3	
	I	4	2	3	
	II				Only 4 representatives of this sub-class in W. T. and all these are stated to be possible products of contact metamorphism.
	II				
	II				
	II				
	II				
	II				

also that the silica contact is much higher in the schist average (65.46) than in the slate average (60.49).

The chemical characteristics of the pelitic foliates cannot, however, be fully inferred from averages, but must be based also on a consideration of individual analyses which furnish a measure of the possible extent of variation in composition. It is instructive, therefore, especially in comparing the pelites with igneous rocks, to treat them for the time being as if they *were* igneous rocks and compute their position in the quantitative system of classification. This has been done for the thirty analyses of pelite schists and gneisses used in these studies, for their average, and for the average of the 79 slate and phyllite analyses. The results are as tabulated in the preceding tables.

The average of the 30 schist analyses falls in class II, sub-class I, order 3, rang 2, sub-rang 3, while that of the 79 slate analyses falls in class II, sub-class I, order 3, rang 4, and sub-rang 2 to 3.

We see from the above table, therefore, that the calculation of the position of these pelitic foliates in the quantitative system serves at once to reveal marked differences between some of them and any known igneous rocks. Others, however, fall in divisions characterized by numerous igneous representatives.

COMPARISON OF COMPOSITON OF IGNEOUS AND SEDIMENTARY FOLIATES

With these preliminary and partial studies of the chemical characteristics of igneous and sedimentary foliates we may proceed to a more minute comparison of the two types with especial reference to the criteria which have been applied by various geologists in distinguishing them. Before taking up the detailed comparisons it may be well, however, to state as clearly as possible the general premises upon which the comparisons are based. These are three in number:

First, Among the meta-sedimentary foliates only the pelites need enter into the comparison. This premise has already been fully considered and will hardly be questioned.

Second, The distinctive chemical characters of the pelites have been developed, not during dynamic metamorphism, but earlier, in the belt of weathering. Most metamorphosed igneous rocks having

never been in the belt of weathering have not been affected by the same kinds of chemical changes.

Third, Both pelites and igneous rocks undergo chemical changes during dynamic metamorphism, but in many if not in most cases, these are not of sufficient magnitude to obscure the original igneous or sedimentary characters. The nature and value of various chemical criteria may therefore be determined by a direct comparison of the pelites with the unaltered igneous rocks as tabulated in Washington's tables. The changes that do take place in igneous rocks during metamorphism appear to be of lesser magnitude and of a different character from those which affect the sediments. Professor C. K. Leith in a letter to the writer has formulated the conception that under conditions of anamorphism, both igneous and sedimentary rocks tend toward a common rock type characterized by a few platy and columnar minerals such as mica, chlorite, talc, hornblende, etc., and that constituents in excess of the proportions necessary to the formation of these minerals will be driven off. To the writer's mind this also involves the conception of a possible *addition* of similar materials to other rocks where their presence may facilitate the development of such minerals. The conception is an interesting and valuable one. From the theoretical standpoint it is necessary to admit the possibility of profound chemical changes as a result of prolonged dynamic metamorphism, and it seems indeed probable that certain rocks now exposed in the older terranes may have been affected by such processes. The point particularly pertinent to the present discussion is the extent to which such equalizing action has gone on among most of the metamorphic rocks with which the geologist has to deal. The evidence already cited seems to the writer to indicate that complete recrystallization with the development of perfect foliated structures *may* take place in both igneous rocks and pelitic sediments, without changes of sufficient magnitude to obscure their original sedimentary or igneous character. Changes in silica content are a possible exception.

The possibility is fully recognized, however, that in certain cases prolonged and severe dynamic metamorphism may produce changes in igneous or sedimentary rocks which render chemical differentiation between them difficult or impossible.

CRITICAL VALUE OF THE ALUMINA CONTENT

The absolute content of alumina in a rock has little critical value unless the proportion be strikingly unusual. What is of significance, however, is its proportion in relation to the bases, lime, and the alkalies, with which, in rocks, it is commonly combined. The high content of alumina in proportion to these bases in the class of pelitic sediments is too well understood to require extended discussion here. It is well known that this arises from two causes, (1) the tendency toward a concentration of alumina in the finer portions, and of silica in the coarser portions of soils and other products of rock disintegration;[1] and (2) the comparatively stable and insoluble character of alumina which leads to an increase in its relative abundance when rocks are acted upon by solutions. In the analyses of metamorphic rocks available to the writer there is no evidence that the proportion of alumina relative to lime and the alkalies varies greatly under conditions of anamorphism such as exist during the development of foliated structures. The increase on the contrary takes place under conditions of katamorphism, especially within the belt of weathering, and is frequently manifest in the development of silicates such as kaolinite, hydro-micas, etc., proportionately richer in alumina and poorer in silica and bases than the more common aluminum silicates of igneous rocks.

In the igneous rocks, lime and the alkalies are the common bases with which alumina is combined, usually in the proportions of 1:1 in the feldspars, muscovite, nephelite, etc. In most igneous rocks alumina is not present in excess of the 1:1 ratio to the available lime and alkalies. In others it exceeds this ratio but the excess is almost invariably small. If in an unweathered foliated rock the excess is large it throws doubt at once upon its igneous origin.

It is a very simple matter to determine the amount of "excess" alumina present in all the superior analyses of igneous rocks tabulated in Washington's tables, since in computing the norm of these rocks for classification according to the quantitative system, alumina is first allotted to K_2O, Na_2O, and CaO in the proportions of 1:1 and the excess of alumina calculated as corundum. The excess

[1] Literature summarized in Failyer, Smith, and Wade, "The Mineral Composition of Soil Particles," *Bull. 54*, Bureau of Soils, U. S. Dept. of Agriculture.

is therefore represented by the percentage of corundum in the norm.

Corundum is present in the norm of 501 out of the 1,892 superior analyses in Washington's tables. Of the 501, 490 belong to the more acid classes I and II.

The corundum in the norm exceeds 5 per cent. in only 52 out of the 1,892 analyses, or less than 3 per cent.

The corundum in the norm exceeds 10 per cent. in only 12 out of the 1,892 analyses, or about $\frac{3}{5}$ of 1 per cent. Of these 12 analyses, 11 fall in sub-class II of the quantitative system in which the ratio of quartz+feldspar+lenads to corundum+zircon is less than $\frac{7}{1}$. Four of the 11 members of this sub-class are stated to be possible products of contact metamorphism and 2 others are a corundum syenite and a corundum pegmatite, respectively.

Among the 30 pelitic foliates which enter into the average given in the table on p. 456 and which are classified in the table on p. 457, 19 show over 5 per cent. of corundum (excess alumina) in the norm and 9 show over 10 per cent. Six of the latter fall in the aluminous sub-class II of the quantitative system. The average of the 30 pelite schist analyses shows 7 per cent. of corundum in the norm and the average of the 79 slate analyses $9\frac{1}{2}$ per cent.

Among the pelites and meta-igneous rocks which have been considered there is no evidence that the alumina content changes materially during the development of foliated structures. It seems safe to conclude therefore:

I. *That a sedimentary origin is to be suspected when the analysis of a fresh foliate shows* Al_2O_3 *in excess of 5 per cent. over the 1:1 ratio necessary to satisfy the* K_2O, Na_2O, *and* CaO *present.*

II. *That when this excess exceeds 10 per cent. a sedimentary origin is extremely probable.*

CRITICAL VALUE OF THE MAGNESIA-LIME RATIO

The importance of carbonation as a phenomena of those portions of the lithosphere in which solution is active has been fully discussed by Van Hise and others. By this process much of the lime and magnesia present in the silicate minerals of igneous rocks becomes converted into the more soluble form of carbonates and suffers partial

removal in solution. The solubility of these carbonates is dependent upon a large number of factors, but in a general way calcium carbonate is more readily soluble than magnesium carbonate. In a rock, therefore, which contains both lime and magnesia, the lime is usually removed more rapidly than the magnesia and the relative amount of magnesia shows a progressive increase.

Since this selective removal of carbonates is largely effected through the agency of circulating waters it is a phenomenon more characteristic of the upper zone of the lithosphere than of the deeper zone in which secondary foliated structures are developed. There appears to be little evidence that the processes which have produced the foliated structures in most of the metamorphic rocks have effected any great changes in the relative proportions in which CaO and MgO are present in the rock, the tendency under these conditions being for these oxides to combine in the more stable form of silicates. If, for example, we compare the percentages of lime and magnesia in the composite analysis of 51 Paleozoic shales made in the laboratory of the U. S. Geological Survey[1] with the percentages shown in the table on p. 456 for the averages of the slate and pelite schist analyses, we find that the relative proportions are closely similar in the three groups. The percentage weights corrected for the water content are given below:

	MgO	CaO
(1) Shales	2.43%	1.48%
(2) Slates	2.61	1.31
(3) Schists and gneisses	2.47	1.53

It appears clear from these comparisons that dominance of magnesia over lime is a feature developed in the pelitic sediments, not during dynamic metamorphism but during the processes of rock disintegration and decay.

A comparison of the pelitic foliates with the igneous rocks as tabulated in Washington's tables gives the relationships with respect to magnesia and lime shown in the first column of the table below.

Among the 79 analyses of sedimentary slates which enter into the average given in the table on p. 456, MgO > CaO in 84 per cent., while among the 30 pelite schist analyses whose average was given in the

[1] F. W. Clarke, *Bull. 330*, U. S. Geol. Survey, p. 468 (1908).

table on p. 456, this relationship holds in 77 per cent. It has already been shown (see table on p. 457) that all of the pelite schists when classified according to the quantitative system fall in the more acid classes I and II and usually near the border between these two classes. A fair comparison of the composition of the pelitic foliates and the igneous rocks should include therefore only the more acid classes I and II among the latter. Among the igneous rock of classes I and II of Washington's tables, MgO exceeds CaO in only 8 per cent., a

	Percentage Weight of $MgO > CaO$	Percentage Weight of $K_2O > Na_2O$	Percentage Weights of Both $MgO >$ CaO and $K_2O >$ Na_2O
Slates	(79) 84 per cent.	(74) 92 per cent.	(74) 78 per cent.
Pelite schists and gneisses	(30) 77 per cent.	(30) 83 per cent.	(30) 74 per cent.
Igneous rocks of classes I and II, Washington's tables*	(1481) 8 per cent.	(1481) 36½ per cent.	(1481) 4½ per cent.
Igneous rocks of classes III, IV, and V	(411) 35 per cent.	(401) 14 per cent.	(401) 7 per cent.

* H. S. Washington, "Chemical Analyses of Igneous Rocks," *Professional Paper No. 14*, U. S. Geol. Survey, 1903.

The figures in parenthesis denote the number of analyses considered in each case.

figure markedly in contrast with the 84 per cent. and 77 per cent. observed in the slates and pelite schists, respectively. For the igneous rocks of the neutral and basic types of classes III, IV, and V in Washington's tables, the number of analyses in which $MgO > CaO$ is about 35 per cent. The *amount* of this dominance is also much greater in many of the basic rocks than in the acid.

Dominance of magnesia over lime is therefore of very considerable value as a criterion of genesis. Its value is greater in the case of acid than of basic foliates.

CRITICAL VALUE OF THE POTASH-SODA RATIO

Attention is frequently called in geological literature to the fact that sodium salts are in general more soluble than the corresponding salts of potash, as an explanation of their more rapid removal from rocks in the processes of weathering. Their rate of removal is not

so much a matter of relative solubility of corresponding salts, however, as of the particular mineral combinations in which soda and potash are most commonly present in rocks. The commonest potash minerals are muscovite and the potash feldspars, orthoclase and microcline. The commonest soda minerals, on the other hand, are the plagioclase feldspars, nephelite, sodalite, etc., which are much more readily decomposed.

The more rapid removal of soda than of potash in the processes of rock weathering is apparent from the comparisons which have been made by Merrill and others[1] of weathered rocks with the rocks from which they have been derived.

Another line of evidence is furnished by analyses of stream and underground waters of areas whose rocks are of known and uniform character. Hanamann[2] found in studying the stream waters of the Erz and Karlsbad mountains in Bohemia that "the tributaries from the granitic highlands are rich in silica, soda, and potash. While in the granites of Bohemia . . . . the soda is to the potash as 1:2, we find that in the waters this ratio is reversed."[3]

The granites of Maine as shown by numerous analyses and field studies[4] contain potash feldspar, orthoclase or microcline, as their dominant feldspar, usually with oligoclase as the subordinate feldspar. The ratio $\frac{K_2O}{Na_2O}$ varies in the available analyses from $\frac{1.3}{1}$ to $\frac{1.8}{1}$. In the ten analyses of groundwaters from the granitic rocks of the state[5] soda dominates over potash in every case, the ratio $\frac{Na_2O}{K_2O}$ varying from $\frac{1.4}{1}$ to $\frac{17.0}{1}$. Of especial interest is an analysis of water

[1] See Geo. P. Merrill, *Rocks, Rock Weathering and Soils*, pp. 185–213 (1906); also Thomas L. Watson, "Granites and Gneisses of Georgia," *Bull. 9–A*, Geol. Survey of Georgia, pp. 298–348 (1902).

[2] Dr. Jos. Hanamann, "Die chemische Beschaffenheit der fliessenden Gewässers Bohmens," *Archiv der naturwissenschaftlichen Landesdurchforschung von Böhmen*, Band IX, pp. 48, 87, 88. This report discusses also the characters of waters derived from other types of rocks.

[3] Translation by the writer.

[4] See T. Nelson Dale, "The Granites of Maine," *Bull. 313*, U. S. Geol. Survey, 1907.

[5] F. G. Clapp and W. S. Bayley, "Underground Waters of Southern Maine," *Water-Supply Paper No. 223*, U. S. Geol. Survey, p. 77 (1909).

from a well on Settlement Hill, two miles northeast of Stonington. The rock of this hill is wholly granite and it is largely bare of drift. The hill which is 120 feet high forms a peninsula connected by a low narrow neck to the main part of Deer Isle. Being thus practically surrounded by the ocean waters, its groundwaters quite certainly derive their mineral content from the granite of the hill. The analysis of water from a well 279 feet deep in the granite here is as follows:

	Parts per Million
Total solids	136.0
Organic and volatile matter	19.0
Silica (SO_2)	11.2
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	2.0
Calcium (Ca)	29.0
Magnesium (Mg)	3.4
Sodium (Na)	13.0
Potassium (K)	1.9
Sulphate radical (SO_4)	26.0
Chlorine (Cl)	17.0

The granite of this hill shows dominant potash with orthoclase-microcline as its dominant feldspar. In the solution of its constituents by the groundwaters the alkali ratio has therefore been reversed. Contamination from sea water is very improbable, not only in the nature of the case, but because of the low chlorine content. The dominance of lime over magnesia in the water is also greater than in the granite, indicating that the lime is being removed more rapidly than the magnesia.

Instances of a character similar to those cited above might be multiplied to show the general tendency for soda to be removed more rapidly than potash in the processes of rock weathering. While this is the general rule exceptions are of course numerous.

There is no evidence of important changes in the potash-soda ratio in the pelitic sediments during dynamic metamorphism and the development of foliated structures. If we compare the percentages of potash and soda in the analysis of the composite sample of 78 shales[1] made in the laboratory of the U. S. Geological Survey, with the

[1] See F. W. Clarke, "The Data of Geochemistry," *Bull. 330*, U. S. Geol. Survey, p. 468 (1908).

percentages for slates and schists given in the table on p. 456, we find, as shown below, that there is no indication of any tendency toward an increase of the $\frac{K_2O}{Na_2O}$ ratio.

	K_2O	Na_2O
Shales	3.42 per cent.	1.38 per cent.
Slates and phyllites	3.44	1.37
Pelite schists and gneisses	3.47	1.93

The comparisons already made between igneous and meta-igneous rocks also reveal no important changes in the potash-soda ratio during dynamic metamorphism. The process is believed therefore to go on largely under conditions of katamorphism and particularly in the belt of weathering.

If we compare the potash-soda relationships in the available analyses of slates and pelite schists with those in the igneous rocks, as was done for the lime-magnesia ratio, the results recorded in the second column of the table on p. 463 are obtained. For reasons already stated (p. 463) a fair comparison includes only classes I and II among the igneous rocks. Among the 74 slate analyses whose average is given in the table on p. 456, in which the alkalies were separately determined, $K_2O > Na_2O$ in 92 per cent., while among the 30 pelite schist analyses considered this relation holds in 83 per cent. Among the 1,481 igneous rocks of classes I and II tabulated in Washington's tables, $K_2O > Na_2O$ in $36\frac{1}{2}$ per cent., while among the 401 rocks of the more basic classes III, IV, and V, the relation holds in about 14 per cent.

The difference in the rates of removal of potash and soda during rock weathering, though less marked than in the case of lime and magnesia, are nevertheless of sufficient magnitude to be of value as a criterion of genesis. Its value is even greater in the case of basic rocks than of acid.

CRITICAL VALUE OF THE DOUBLE RELATIONSHIP $MgO > CaO$ AND $K_2O > Na_2O$

If we examine the slate and pelite schist analyses which enter into the averages of the table on p. 456, we find that there is a dominance of MgO over CaO and also of K_2O over Na_2O in 78 per cent.

of the slate analyses and 74 per cent. of the pelite schist analyses. In the igneous rocks of Washington's tables this double relationship holds in only $4\frac{1}{3}$ per cent. of the rocks of classes I and II and in 7 per cent. of the rocks of classes III, IV, and V. These relations are tabulated in the third column of the table on p. 463. The double relationship is therefore of much more diagnostic value than either of the single relationships. If we consider the pelites in comparison with the igneous rocks of classes I and II, the double relationship has about twice the critical value of dominance of only MgO over CaO, and over eight times the value of dominance of only K_2O over Na_2O.

CRITICAL VALUE OF THE SILICA CONTENT

Attention has already been called to the fact that certain types of metamorphosed sediments, such as quartzites and quartzitic schists, are usually readily identified as such from their highly quartzose character without the necessity of further chemical study. There is however every variation from such extremely siliceous types to typical pelites, and it is to be expected that in many of these intermediate types the high silica content will have diagnostic value.

It has been shown that the Al_2O_3 content, the $\frac{MgO}{CaO}$ ratio, and the $\frac{K_2O}{Na_2O}$ ratio in a rock exhibit no important change during dynamic metamorphism. The SiO_2 content, on the contrary, often increases very markedly during metamorphism. This is shown by a comparison of the average of the pelite schist analyses with the slate average in the table on p. 456. A discussion of the cause of this silication is beyond the scope of this paper. It has usually been explained as a process complementary to decarbonation, CO_2 being driven off during dynamic metamorphism and carbonates converted into silicates. Studies which the writer has in hand have led him to believe, however, that while silication as a result of decarbonation undoubtedly takes place, it is quantitatively inadequate to explain the large silica increases observed. It seems probable that there is actual addition of silica from outside, either through the agency of descending groundwaters or from magmatic sources. The comparisons of igneous with meta-igneous rocks which have been given in this paper afford slight and

inconclusive evidence of silication in metamorphism. The process is so marked, however, in the case of the pelites that it seems probable it may also assume important magnitude in the metamorphism of certain igneous rocks.

High silica content as a criterion of sedimentary *versus* igneous origin must therefore be used with more reservation than the other criteria we have considered, since it may be developed in an igneous rock during metamorphism. Used in connection with other criteria it may have very considerable confirmatory value. Used alone it is of very questionable value.

As in the case of alumina, it is not the percentage as given in the analysis that is significant, but the excess silica remaining after silica has been allotted to the bases present in the proportions in which it is usually present in the common rock-making minerals. This excess silica appears as quartz in the norm when the rock is classified according to the quantitative system.

The amounts of "excess" silica characteristic of igneous rocks may be inferred from the following comparisons of the analyses tabulated in Washington's tables:

In class I, only 25 analyses show over 50 per cent. of quartz in the norm and only 7 analyses show over 60 per cent. out of the 762 tabulated.

In class II, only 14 analyses show over 30 per cent. of quartz in the norm and only 1 analysis shows over 40 per cent. out of the 719 tabulated.

In classes III, IV, and V, none show over 15 per cent. of quartz in the norm.

As an example of the critical value of the silica content we may take the case of a foliated rock which falls in class I of the quantitative system and which shows evidence of sedimentary origin, either in its magnesia-lime ratio or its potash-soda ratio or both. If in the norm of this rock the quartz content exceeds 50 per cent. the evidence of its sedimentary origin is greatly strengthened. If the quartz exceeds 60 per cent. the evidence of sedimentary origin is even stronger.

It is to be noted that among the 30 pelite schist analyses classified in the table on p. 456, two are so quartzose as to fall in order 2 of class II where the ratio of quartz to feldspars in the norm is $>\frac{5}{3}$. There are

no representatives of this order among the igneous rocks of Washington's tables. Others among these schists show quartz in excess of the proportions given above as characteristic of igneous rocks.

EXAMPLES OF THE APPLICATION OF CHEMICAL CRITERIA

In conclusion, the application of the criteria which have been considered to certain type examples may aid in a fuller understanding of the principles involved.

The two gneisses described by Adams[1] from St. Jean de Matha and from Trembling Lake in Quebec show both a dominance of MgO over CaO and of K_2O over Na_2O. Both show more than 10 per cent. of corundum in the norm and thus fall in sub-class II of class II, characterized by only 4 doubtful analyses in Washington's tables. Adams' conclusion that they are of sedimentary origin would appear therefore to be well grounded.

	1	2	3	4
SiO_2	60.33%	64.89%	78.90%	78.28%
Al_2O_3	20.85	13.10	12.20	9.96
Fe_2O_3	3.59	4.99	2.30	1.85
FeO	4.47	0.99		1.78
MgO	2.07	2.73	0.75	0.95
CaO	1.82	1.95	0.25	1.68
Na_2O	1.38	3.68	2.36	2.73
K_2O	2.84	5.46	0.24	1.35
H_2O+	2.78	1.60	1.90	0.83
H_2O-		0.12		0.12
BaO	....	....	....	....
TiO_2	1.41	0.98	0.50	0.70
Total	101.82%*	100.49%	99.40%	100.44%†

* Includes P_2O_5—0.28 per cent.

† Includes P_2O_5—0.11 per cent., MnO—0.08 per cent., and BaO—0.02 per cent.

No. 1. Gneiss from near Jenkintown Junction, Penn. Described as containing garnet, mica, feldspar, and magnetite. F. A. Genth, Jr., analyst, *Penn. Geol. Survey Report*, C^6, p. 122.

No. 2. Muscovite-biotite gneiss from Pfelderstal, Tirol. Paul Seidel, *Beiträge zur Kenntnis der gesteinsbildenden Biotite*, Borna-Leipzig, p. 47, 1906.

No. 3. Muscovite gneiss from near Zell in the Fichtelgebirge, Bavaria. Rosenbusch, *Elemente der Gesteinslehre*, 2d ed., p. 488 (1901). For calculation of the norm the iron is apportioned as Fe_2O_3—1.32 per cent.—and FeO—0.98 per cent.—which is about the ratio of the two oxides in the average of the pelite schist analyses.

No. 4. Gneiss, Great Falls, near Washington, D.C., *Fifteenth Ann. Rept.*, U. S. Geol. Survey, p. 670 (1895).

[1] *American Journal of Science*, 3d series, Vol. L, p. 67 (1895).

A mica gneiss from near Jenkintown Junction, Pa., has the composition shown in Analysis No. 1 of the preceding table. When this rock is classified according to the quantitative system it is found to fall in class II, sub-class II. This sub-class is characterized by unusually high alumina content and has only four doubtful representatives in Washington's tables. The amount of corundum in the norm which is 12 per cent. is highly indicative of sedimentary origin. The presence of quartz in the norm to the extent of 33.18 per cent. is also somewhat suggestive of sedimentary origin. The double relationship of dominance of MgO over CaO and of K_2O over Na_2O is also shown. The sedimentary origin of this gneiss may therefore be regarded as beyond reasonable question.

Analysis No. 2 of the same table shows the composition of a muscovite-biotite gneiss from Pfelderstal in the Tirol, which is stated to be of sedimentary origin. The alumina content is of no critical significance in this case, no "excess" alumina being present. The silica-content is also without critical value, since the rock falls in class II of the quantitative system and shows only 15.90 per cent. of quartz in the norm. The double dominance of MgO over CaO and of K_2O over Na_2O is however sufficient evidence to render a sedimentary origin highly probable.

Analysis No. 3 of the same table shows the composition of a muscovite gneiss stated to be of sedimentary origin, from the Fichtelgebirge in Bavaria. In this the potash does not dominate over the soda and although magnesia dominates over calcium yet the percentages of both are so small that this relation has less than the usual significance. A calculation of the position of this rock in the quantitative system places it in class I, sub-class I, order 2, and rang 4. Among the igneous rocks of Washington's tables there are no representatives of this rang, the percentage of lime being abnormally low in comparison with the alkalies. The attempt to classify this rock therefore serves to show at once its entire difference from any known igneous rocks. The alumina content is also suggestive of sedimentary origin, corundum being present in the norm to the extent of 7.55 per cent. The silica content is also significant, the 62.40 per cent. of quartz present in the norm being much in excess of that commonly found among the igneous rocks of class I. Sedimentary

origin is here indicated by three chemical criteria and may therefore be regarded as well established.

Analysis No. 4 shows the composition of a gneiss from the Great Falls of the Potomac near Washington, D. C. This rock was described by George H. Williams[1] and was believed by him to be of sedimentary origin. He says: ". . . . the analysis . . . . has no relation to any known igneous type, but agrees quite closely with certain siliceous sediments; so that, so far as the chemical evidence can be relied upon, we may safely regard the rock as of sedimentary origin."

The analysis of this rock shows neither a dominance of MgO over CaO nor of K_2O over Na_2O. There is also no excess of alumina above the amounts common in igneous rocks, less than 1 per cent. of corundum being present in the norm. The amount of quartz present in the norm is 52.14 per cent. This quartz percentage might be somewhat suggestive of sedimentary origin if supported by other criteria, but taken alone has little critical value for the reasons given on p. 468. This rock falls in class I, sub-class I, order 3, rang 2, and sub-rang 4, of the quantitative system, a subdivision numbering 16 other representatives in Washington's tables. In the opinion of the writer this analysis affords no valid evidence of sedimentary origin.

SUMMARY AND CONCLUSIONS

The chemical analysis, while in some cases of no critical value, is in many other cases a valid means of determining whether a foliated rock is of sedimentary or igneous origin.

The utility of chemical data depends upon the facts that the chemical characteristics of greatest critical value are developed in the belt of weathering during rock disintegration and decay, and that in very many of the igneous as well as the sedimentary rocks the chemical changes during the development of foliated structure are relatively slight.

In so far as igneous rocks have been affected by the processes of weathering either before or after the development in them of foliated structures, they tend to approach the sedimentary rocks in composition, and the criteria outlined in this paper become invalid.

[1] *Fifteenth Annual Report*, U. S. Geol. Survey, p. 670

For this reason only fresh foliated rocks should be used in chemical studies undertaken for the purpose of determining genesis.

In the case of foliates of *plutonic* igneous origin, weathering before the development of the foliated structure is believed to have affected so small a proportion of the rocks of this class that it is practically negligible for the purposes of this discussion.

Foliates of *volcanic* origin may in many cases have been subject to weathering for considerable periods previous to the dynamic metamorphism which developed their parallel structures. In so far as extensive weathering has taken place, their differentiation from sediments on chemical grounds will be uncertain. It is probable, however, that in the majority of cases, weathering in rocks of this type has not been sufficient to obliterate their igneous characters.

Dominance of MgO over CaO is strongly indicative of sedimentary origin.

Dominance of K_2O over Na_2O is of lesser critical value, but is nevertheless suggestive of sedimentary origin.

The double relationship of dominance both of MgO over CaO and of K_2O over Na_2O affords very strong evidence of sedimentary origin.

The presence of any considerable excess of Al_2O_3 in the analysis over and above the 1:1 ratio necessary to satisfy the lime and alkalies, is also suggestive of sedimentary origin.

High silica content may be indicative of sedimentary origin when supported by other criteria. This criterion must, however, be used with caution, since silication probably takes place in the dynamic metamorphism of certain igneous rocks.

When three or all of the above relationships hold good, the evidence of sedimentary origin may be regarded as practically conclusive.

WASHINGTON, D. C.
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THE METAMORPHISM OF GLACIAL DEPOSITS[1]

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INTRODUCTION

Glacial drift metamorphosed to a conglomerate has been studied in several parts of the world. A detailed description of such a conglomerate in South Australia, identified as a Cambrian tillite, has recently appeared;[2] glacial formations of the same period have been studied in China.[3] In India,[4] Africa,[5] and South Australia,[4] glacial conglomerates of Permian age have been carefully investigated.

[1] Published by permission of the Ohio Geological Survey, but the author is responsible for the opinions expressed. Read before Section E of the American Association for the Advancement of Science at Baltimore, 1908.

[2] Rev. Walter Howchin, "Glacial Beds of Cambrian Age in South Australia," *Quart. Jour. Geolog. Soc.*, Vol. LXIV (1908), pp. 234–59. The same author made a preliminary report in 1901, *Trans. Roy. Soc. of South Australia*, Vol. XXV, p. 10.

[3] Willis, Blackwelder, and Sargent, *Research in China*, Vol. I (1907). Carnegie Institution, Washington.

[4] C. D. White, *American Geologist*, Vol. III (1889), pp. 306–11. Chamberlin and Salisbury, *Geology*, Vol. II (1906), pp. 632–35.

[5] C. D. White, *op. cit.*, pp. 303–6. Chamberlin and Salisbury, *op. cit.*, pp. 635–38.

The present brief inquiry is confined to glacial sediments of the Pleistocene period. The conclusion arrived at, from a field study of these sediments in central New York and in northern and central Ohio, is that locally, at least, the alteration of a part of the drift is under way, that is, it has reached an appreciable stage of metamorphism; furthermore, that this fact may be used in differentiating the drifts of some of the Pleistocene epochs.

In this paper the term "metamorphism" includes all alterations concerned in the transition from degradational products to solid rock again.[1] It is not possible to observe many stages in this cycle because of the fact that so far as present investigation goes, the glacial periods are separated by long lapses of time, and because of the further fact that most phases of metamorphism require a physical environment that precludes observation.

FIELD DATA

The glacial deposits that occasioned this study are characterized by the following features:

1. *Color.*—All the unmodified drift concerned is bluish; it is felt that this is the constant color of the deposits because the observations were made either along stream banks that were being undercut, thus giving fresh exposures, or along shore cliffs where the waves are undermining the drift. In most of the exposures the color condition is emphasized by contact with drift which differs in color; the usual association is a yellow and sometimes oxidized horizon of more recent glacial accumulation beneath which is the zone of bluish drift. So far as can be ascertained, the color is not dependent upon the content of the drift. The surfaces of the included bowlders, large and small, and the entire matrix of clay, are uniformly of a bluish cast. This characterization applies equally to these deposits in widely separated parts of Ohio as well as throughout a considerable region of central New York. Because of a lithological difference in the rock formations that were eroded, as shown by a study of the bowlders and pebbles in the drift, one would expect some variation in color; this, however, is not the case.

2. *Texture and structure.*—As is the case with nearly all types of

[1] C. K. Leith, *Journal of Geology*, Vol. XV (1907), p. 313.

glacial deposits, we have here a great variety in texture. The till of some exposures is very fine, and quite free of even small bowlders; other exposures contain many, and large, erratics. More uniformity in texture, however, is found in the water-laid drift belonging to this study; usually, it is fine, even silty.

All these deposits apparently show the effects of great and long-continued pressure. They are dense in structure. This compactness is manifest in the angle at which the cliff-faces stand, not infrequently overhanging; also in the tendency of bowlders, showing on the surface of the cliffs, to hang even after more than half their mass has been exposed. In some cases I was able to satisfy myself, by tracing this hard horizon back from the cliff, that it constituted the proverbial "hard pan" of well-drillers. Furthermore, I have seen several dug wells being made, in which case there could be no doubt about the identity of this compact horizon and the bluish till.

3. *Obvious physical alteration.*—In several cliff-exposures the contact between this hard deposit and the superjacent drift is a series of sags and swells representing either an irregular deposition of the subjacent material or its unequal erosion later (Fig. 1). But the relation of the inequalities precludes subaërial erosion; the irregular surface is either genetic, or it was produced by the erosion of overriding ice.

Contortion and folding is observed particularly in the water-laid deposits (Fig. 2). This alteration has been studied in material varying from silt to rather coarse sand. I have examined many exposures, both modified and unmodified, which show jointing and faulting (Figs. 3, 4, 5). In no case was I able to show conclusively a displacement of more than three inches, and this maximum displacement was always in the water-laid drift. It is quite impossible to measure movement along a fault-plane involving only till. On the theory that every joint is a fault,[1] we may assume a displacement even though it cannot be measured. In all exposures of till thus altered, the joints are nearly vertical, and in systems (Fig. 6). In the water-laid deposits this characterization is less clear. It should be stated, furthermore, that along most of the joint-planes or fault-

[1] G. F. Becker, *Bulletin of the Geological Society of America*, Vol. IV (1893), p. 72.

Fig. 1.—Buried valley west of Cleveland. At the base is bluish till, apparently ice-eroded; above is compressed and slightly distorted silt.

planes there has taken place either a secondary alteration or a deposition from percolating water (Fig. 2). In some cases this secondary deposit has weathered away more rapidly than the wall material; in others, less rapidly.

4. *Weathering.*—Leaching in a relatively short time removes carbonates, especially from surface deposits. Only at a considerable distance from the top do we often get evidence of carbonates in the superjacent drift. This leaching by ground water is the first step in the cementation process always going on at lower horizons. The bluish compressed drift invariably shows the presence of calcium carbonate. This fact does not imply that the drift had never lost its carbonates through leaching; it means only that now this particular cement is present, deposited probably from solution. No further observation was made to determine the cements or other chemical content of this dense drift. It is tentatively assumed that the universal bluish color is a result of alteration, though it cannot be disproved that this drift in both New York and Ohio was not bluish from the time it was deposited, but the force of this possibility is somewhat lessened by the fact that there is considerable difference in the content of the drift of these areas; it is assumed, further, that this color probably represents a chemical alteration accompanying metamorphism, a change brought about, under particular conditions, by ground water in unconsolidated sediments. The nature of these conditions will be discussed later.

The superjacent yellow till usually shows the results of weathering, especially near the surface; but in all parts there is evidence of leaching.

AGENCIES OF ALTERATION

Normally most of the changes going on in the regolith are due to pressure and to chemical reactions. The pressure is that of the superincumbent mass which varies directly with the depth. Chemical reactions are chiefly associated with water which is always a solvent, but the water of glacial drainage, since it comes in contact with such a wide range of rocks, is highly solvent and has capacity for other chemical reactions.

Chemical.—Outside of arid regions, sediments contain a good deal

FIG. 2.—Deposits in a buried river valley west of Cleveland; this material was crumpled and distorted; later it was faulted; vein deposits occupy the fault-planes.

of water. In all climates circulating ground water exists at some depth; the more humid the climate, the higher is the ground-water level. It is probable, however, that a special condition exists in sediments subjacent to an ice-cap; here, on account of the constant melting of the basal ice caused by radiation from the earth,[1] the supply of water is so great that a condition of saturation exists in these sediments. This condition of saturation was certainly the case during both the advance and retreat of the ice-sheet within the north-sloping side of the St. Lawrence drainage basin. This northward slope in conjunction with the wall of ice caused a ponded condition of drain-

FIG. 3.—Disturbed and faulted bluish till exposed along Dugway Brook, Cleveland.

age. Beneath these bordering lakes, sediments were always in a condition of saturation.

Underneath an ice-sheet, it is reasonable to suppose that oxidation is subdued, but even in the absence of atmosphere, sulphides may be slowly changed to sulphates. Since this glacially accumulated rubbish may contain constituents previously weathered, it is possible that deoxidation also takes place.

Throughout the distance between the Mohawk Valley in New

[1] Chamberlin and Salisbury, *Geology*, Vol. I (1904), p. 263.

FIG. 4.—Jointed bluish till on shore of Lake Erie at Conneaut, O. The cliff-face is a joint-plane at right angles to the two conspicuous joints.

York state and Michigan at the western end of Lake Erie, limestone formations come to the surface. These outcrops suffered degradation by the ice-sheet. Other limestone horizons farther north, in part of this distance, also contributed to the glacial load of débris. This content of limestone in glacial sediments was partly dissolved even by the cold water; no rock-forming constituent is more easily affected by water. The resulting carbonated water actively attacked the silicate minerals at least. Solution and later precipitation is always an accompaniment of ground-water circulating through glacial sediments, and further reactions will give different solutions.

The decomposition of rock-constituents is usually accompanied by hydration. This is almost invariably the case in oxidation and carbonation. In unconsolidated materials beneath an ice-cap hydration would be an active agent in alteration.

Pressure.—In the deeper-seated areas of the fragmental zone of the earth's crust, pressure has long been regarded as playing an active part in the alteration of rock. In the case of the superficial sediments under discussion there appear to be three sources of pressure:

1. The weight of drift overlying a given horizon in a mass of sediments exercises a compressive force; in the deeper-buried sediments this force is stronger. In consequence of this compression there is greater facility in capillary action, that is, waters move more slowly through these sediments, and precipitation is increased.

2. During the continuance of an ice-invasion, the weight of the ice itself bore down on the unconsolidated materials, thus acting as a factor in their alteration. In discussing this, however, it must be granted that an ice-sheet degrades, first of all, the regolith. It is a fact nevertheless that in certain localities, some of the previously aggraded sediment was not removed by ice.[1] These deposits may be the drift of an earlier ice-invasion; in any case, wherever not removed, it was subject to the great weight of the ice-sheet. This weight can be computed only approximately. Some observations have been made on which are based conclusions in reference to the surface slope of ice-caps; this data includes a study of both existing

[1] R. S. Tarr, *American Geologist*, Vol. XXXIII (1904), p. 287. H. L. Fairchild, *Bulletin of the Geological Society of America*, Vol. XVI (1905), pp. 53–55. F. Carney, *Journal of Geology*, Vol. XV (1907), pp. 579, 580.

FIG. 5.—Jointed bluish till on shore of Lake Erie, east of Cleveland.

ice areas and bands of drift constructed by former ice.[1] A conservative estimate of the depth of Wisconsin ice over the Erie basin is at least 2,000 feet. This figure is based on two considerations: the present difference in level between Lake Erie and altitudes south that were covered by ice is about 800 feet. The ice reached south of the Erie basin approximately 200 miles; if its surface sloped even six feet per mile, this would represent a depth of 1,200 feet which, plus the 800 feet due to the difference in altitude, makes approximately 2,000 feet. The basal pressure per square foot for clear ice of this thickness would be 115,500 pounds.

In New York state, there is a greater difference in altitude, even when we neglect the overdeepened portions of the major Finger Lake valleys. The range in altitude alone would give 1,500 feet of ice; this, in connection with the surface slope of the ice, would give a depth of approximately 2,500 feet, which represents a basal pressure per square foot of over 144,000 pounds. Both these computations, it is noted, are for clear ice. Knowing that the ice-sheet must have carried constantly some drift, these figures undermeasure, perhaps, the real pressure. That the subjacent deposits would be compressed by the weight of this ice is undebatable.

Adams has shown that a condition of rock-flowage was induced in marble by a pressure of about 18,000 pounds per square inch.[2] The pressure on the sediments, as discussed above, is in either case more than 9,000 pounds per square inch.

Another possible factor associated with the question of pressure is the development of heat. Even the laggard motion of an ice-sheet represents energy which through basal interference is converted into heat. This heat may have no other manifestation than the wastage of ice near the friction zone. Whether a dead load upon compressible matter evolves heat in the absence of appreciable movements along planes developed in this matter is a question on which the writer is not informed.

3. It is thought, furthermore, that pressures are evolved by chemical changes going on in this drift. Such pressure is an accompaniment of hydration when the hydrated mineral is confined as must be the

[1] Chamberlin and Salisbury, *Geology*, Vol. III (1906), pp. 356–58.

[2] F. D. Adams, *Bulletin Geological Society of America*, Vol. XII (1901), p. 457.

FIG. 6.—Water-laid drift overlying bluish till which contains two systems of vertical joints. This till is very stony, mostly limestone.

case in drift subjacent to a burden of at least 9,000 pounds per square inch. Other chemical changes also tend to increase the bulk of the minerals being altered.

SUMMARY

In defining its age and origin the most suggestive feature of this drift is its color which is constant over widely separated areas. The folding, jointing, and faulting might be caused by Wisconsin ice readvancing over drift it had recently deposited; faulted sediments subjacent to till of such a readvance are shown in Fig. 7.

Fig. 7.—Faulted glacial gravels. Yellow till has been removed from the top.

It is possible that the bluish till is the product of the oncoming Wisconsin ice. If the pressure of an ice-cap is the most active agent of alteration, and the time factor is secondary, it is even probable that both the bluish and yellow drifts are Wisconsin; but the following observations tend to diminish this probability:

About three miles northeast of Newark, O., along Shanee Run, and again two and one-half miles southeast of Newark along Quarry Run, I have seen the same bluish till, at the former outcrop in contact with the yellow drift, at the latter showing only in the bed of the stream

where it forms a riffle. These localities are just within the margin of the Wisconsin drift, where the ice was attenuated as well as short-lived. It is certain that in these two cases time has been the important factor in the alteration; no great mass of ice ever stood here for even a short period. If this hard bluish till was deposited by Wisconsin ice, its color is genetic; but on this hypothesis it is difficult to understand why the superjacent drift is yellowish, and the line of division is so sharp.

But there can be no question that the old valley of Rocky River, west of Cleveland, was buried by a pre-Wisconsin ice-invasion, presumably the Illinoian. The bluish till in this buried stream-course is apparently identical with the dense drift referred to in central Ohio and New York.

These facts suggest the following conclusions:

1. Glacial deposits, regardless of their constituents, when buried for a long time appear to become compact, and bluish in color. This assumption does not disregard the possibility that some deposits have always been bluish. The dozens of exposures studied in both states show a great variety of rock-constituents, as well as wide variation in the general texture of the drift; this color is constantly noted in drift ranging from fine silt to an extremely stony till (Figs. 1, 2, and 6[1]). I have nowhere noted a gradual blending from one color to the other, nor streaks of the yellow penetrating the bluish, as has been described in the Central West.[2] It is very likely that upon sufficient exposure to weathering agents the blue till would become lighter in color; but because of its indurated condition it weathers less rapidly than does the superficial Wisconsin drift.

2. An ice-cap passing over glacial sediments, particularly till, develops in it joints and faults (Figs. 2–4) either because the till on account of inconstancy in structure yields differentially to the weight, or because differential strains are induced by topography; these fracture lines are approximately vertical (Figs. 5, 6). I have observed

[1] Cf. *Journal of Geology*, Vol. XV (1907), pp. 575, 577, for other pictures illustrating the same variation in texture.

[2] F. Leverett, *Monograph XLI*, U. S. Geolog. Surv. (1902), p. 272. *Ibid., Monograph XXXVIII*, U. S. Geolog. Surv. (1899), p. 28. W. H. Norton, *Iowa Geological Survey*, Vol. IX (1898), pp. 480–82.

this jointed condition of till in central and northern Ohio, and in New York along creeks tributary to the outlet of Keuka Lake.[1]

3. The altered drift described in this paper contains abundant carbonates, probably deposited from circulating ground water, whereas carbonates are either absent or less conspicuous in the superjacent drift of later origin. This difference between the two drifts is apparent even when tests are made near their contact; the observation holds for exposures studied in all the areas under consideration.

4. The color in the case of the drift above described, its indurated condition, and the jointing appear to be associated with the change or metamorphism which develops tillite from glacial drift.

5. I believe that so far as the regions considered in this paper are concerned two Pleistocene epochs are indicated by a contact of the bluish and yellow till.

[1] *Journal of Geology*, Vol. XV (1907), pp. 583, 584.

Reviews

The Natural History of Igneous Rocks. By Alfred Harker. New York: Macmillan, 1909.

The scope of Harker's *Natural History of Igneous Rocks* may be indicated by the titles of the chapters which are as follows: (i) "Igneous Action in Relation to Geology;" (ii) "Vulcanicity;" (iii) "Igneous Intrusion;" (iv) Petrographical Provinces;" (v) "Mutual Relations of Associated Igneous Rocks;" (vi) "Igneous Rocks and Their Constituents;" (vii) "Rock-Magmas;" (viii) "Crystallization of Rock-Magmas;" (ix) "Supersaturation and Deferred Crystallization;" (x) "Isomorphism and Mixed Crystals;" (xi) "Structures of Igneous Rocks;" (xii) "Mineralisers and Pneumatolysis;" (xiii) "Magmatic Differentiation;" (xiv) "Hybridism in Igneous Rocks;" (xv) "Classification of Igneous Rocks."

The author emphasizes the correlation between the general geologic history of a given region and the igneous activity in the same region, which he makes on the general basis of the idea that igneous action is a result of crustal movements, and the further idea that these movements produce magmatic differentiation over continental areas; thus leading to magmas of different composition in regions affected by different kinds of crustal movements. It becomes apparent, therefore, that the author accepts the idea of differentiation, and applies it as a means of explaining the distribution of igneous rocks in all parts of the earth's crust, whether those parts be treated in detail or on the largest scale. It follows as a natural consequence that he explains petrographic provinces as due to differentiation over large areas, while the different types of a given province are explained as due to differentiation within that province.

On the other hand, Harker accepts Vogt's conclusion that silicates, silica, and water are miscible in all proportions at the temperatures of magmas, and that consequently there can be no liquation or spontaneous division of a single magma into different parts while the whole is still liquid; except insofar as such a division may be explained by differences in pressure, temperature, or density. He further concludes that the liquation due to pressure and density would be negligible in amount, while he thinks the differential action of gravity would perhaps suffice to concentrate the denser constituents in the lower portion of a large magma. With this possible exception he attributes differentiation to the concurrent

action of crystallization and diffusion, not accepting Becker's conclusion that diffusion would proceed so slowly as to be ineffective except for very short distances.

In chaps. vi–x, Harker discusses the crystallization of rock-magmas from their constituents on the basis of new data developed by Vogt, Tamman, Day, Allen, Wright, Adams, and others. He applies to the solution of the problems involved, the principles of physical chemistry as developed by Roozeboom, Ostwald, and Van't Hoff, and concludes that textures are in part due to these laws, and to the relation of the actual composition of the magma to that of the dominant eutectic.

In discussion of hybridism Harker denies the importance of magmatic assimilation except on the smallest scale and considers hybrid rocks to be a minor factor in the history and development of any igneous complex.

In his last chapter the author makes no attempt to present a new classification of rocks, although he says that the American quantitative classification marks a "retrograde movement, for here the artificial element is applied to the complete exclusion of the natural." He believes that the time is not yet ripe for a natural classification of igneous rocks, although he agrees with Becker that such a classification will probably be based upon the eutectics occurring in rocks, and he suggests further that it will involve the mode of development of various rock-types from a single parent magma through the action of differentiation; thus developing something which is comparable to the principle of descent used in the classification of animals and plants.

It appears therefore, that the book is an excellent summary of our present knowledge, and well suited for use with advanced students of petrology.

A. N. W.

Cambrian Geology and Paleontology. By CHARLES D. WALCOTT. Cambrian Sections of the Cordilleran Area. From *Smithsonian Miscellaneous Collections,* Part of Vol. LIII, pp. 167–230. Ten plates. Washington, December 10, 1908.

This paper is a continuation of Dr. Walcott's study of the Paleozoic rocks of western North America. The object of this preliminary correlation is to show the interrelations of the Cambrian strata and faunas in the Cordilleran area, particularly in California, Utah, Nevada, Montana, and British Columbia. Five generalized sections are described in detail as to character and content. There seems to be a close relationship

between the Cambrian of Shantung, China, and the Cordilleran sections which the author will discuss in a future paper upon the Cambrian faunas of China.

C. J. H.

Studies of Frost and Ice Crystals. By WILSON J. BENTLEY. Reprinted from the *Monthly Weather Review* for August, September, October, November, and December, 1907. Jericho, Vt., 1907.

This interesting memoir on frost and ice crystals deals with their forms, structure, life-history, and general relations. It contains twenty pages of descriptive matter and thirty-one plates.

C. J. H.

Lime and Cement Resources of Missouri. BY H. A. BUEHLER. Missouri Bureau of Geology and Mines, Vol. VI, 2d Series. 255 pp., 35 pls., map. Jefferson, 1907.

This report describes the raw materials used in the manufacture of lime and cement; their uses, properties, and methods of manufacture; also a general description (by counties) of the formations affording these materials.

C. J. H.

Geology and Physical Geography of East Greenland. BY OTTO NORDENSKJOLD. Reprinted from "Meddelelser om Grönland," Vol. XXVIII, pp. 153–285, 4 colored plates. Copenhagen, 1908.

This reprint contains some of the observations of the Danish expedition of 1900. Many rock specimens were collected for petrographical study. The great central rock-mass of Greenland is crystalline, principally composed of primary gneisses, schists, syenites, porphyries, and basalts. Their age is early Archean. Around the central mass is a fringe, 50 to 75 miles wide, of sedimentaries, the oldest being Silurian. They are quite fossiliferous. Both the crystallines and the sedimentaries show the effects of extensive vulcanism.

The physiographic features described are: the fiords, the non-glaciated southern part of Jamesland, those of the coast-border, the central mass configuration of the country by glaciation, and fault valleys. C. J. H.

Cobalt-nickel Arsenides and Silver Deposits of Temiskaming. (3d ed.) By Willet G. Miller. Report of the Bureau of Mines, 1907. Vol. XVI, Part II, 212 pp., 4 maps, and 100 illustrations. Toronto, 1908.

This report brings the mining situation of the region clearly before the public. Conditions have adjusted themselves to a working basis and stock-jobbing has almost ceased. The oldest rocks of the area are the Keewatin into which is intruded the Laurentian granite. Unconformably on these is the Lower Huronian conglomerate and slates. The Middle Huronian lies unconformably on the Lower. Finally there was a large intrusion and extrusion of basic rocks in Keeweenawan time. Associated with the diabase and on its outer edge are the ore-bearing veins. Occasionally they are found running out into the Keewatin green-schists. The width given for the veins is 14 inches or less. At Silver Islet they have been worked to a depth of 1,200 ft.

The ores present are: native silver, smaltite, cobaltite, niccolite, chloanthite, millerite, argentite, pyrargyrite, proustite, dyscrasite, native bismuth, tetrahedrite, chalcopyrite, bornite, mispickel, pyrite, galena, asbolite, and zinc blende. The following occur in the oxidized zone: native silver, erythrite, and annabergite. Native silver and smaltite are the important ones. The origin of the ores is still unknown. The total value of ore produced up to 1908 was $10,000,000, of which 50 per cent. was profit.

The report contains descriptions of the most important mines also an appendix giving a list of companies incorporated during 1904–8, and an early history of the cobalt industry in Saxony. C. J. H.

Some Relations of Paleogeography to Ore Deposition in the Mississippi Valley. By H. Foster Bain. Mexico, 1907.

The ore deposits are chiefly lead and zinc which are in no way related to vulcanism. The Wisconsin district is considered in detail. The present ore bodies are believed to be the result of reduction of sulphates to sulphides by reactions between ore-bearing solutions and organic matter in the country rock. Sulphurization of carbonates has also taken place. Original precipitation of the material from the sea water was likely due to the same reactions. Original localization may have been due to: (1) local abundance of the metals in solution; (2) local abundance of the organic reducing matter; (3) locally peculiar organic matter leading to particular efficiency in producing deposition.

The local abundance of lead and zinc in solution may have accumulated

along the shore from streams draining areas of the crystalline rocks to the north in which the metals were unequally distributed. The evidence supporting this is, that certain ore basins resemble in shape the embayments at the mouths of streams, or drowned river valleys. Further, there are considerable quantities of mechanical sediments within them, but not elsewhere. The source of the reducing agents is the bituminous shale, "oil rock." This rock contains only partially decomposed plants even now giving off complex hydrocarbons of great reducing power. This rock occurs in irregular patches which were probably determined by the unicellular plants accumulating in quiet protected places. As the rock decomposed the decrease in volume gave rise to small depressions in larger ones. The settling produced pitching crevices and features, which allowed circulation of volatile matter and solutions, the result being concentration of lead and zinc ores.

C. J. H.

Tertiary Plants of British Columbia. Collected by L. M. Lambe in 1906. Discussion of Previously Recorded Tertiary Floras. By D. P. Penhallow. Ottawa, 1908.

The Tertiary deposits of western Canada are mainly in British Columbia, Alberta, and Saskatchewan, with important outliers to the northward and westward. Two hundred and seventy-one species and genera of plants were collected. They are of Eocene, Oligocene, and Miocene age. They fall into two groups, one distinctly Eocene, the other Miocene or Oligocene. Their stratigraphical distribution is given in a series of tables. Tertiary formations of B. C., at present, cannot be regarded as more recent than the Lower Miocene, the greater portion being Oligocene. Further the beds are superimposed in part upon the older Tertiary of Lower Eocene, Upper Laramie, Fort Union, or Lignite Tertiary age which immediately overlies the Cretaceous. These beds extended east as far as Turtle Mountain in Manitoba, but were separated from the western by the Rocky Mountain uplift in Miocene time.

C. J. H.

West Virginia Geological Survey. Vol. II (A), 1908. Supplementary Coal Report. By I. C. White, State Geologist. 720 pp., map.

The volume is largely a compilation of descriptions of many sections taken from the various coal-fields of the state. Certain errors in correlation in Vol. II are corrected. The stratigraphical position of the various coal-beds, formations, and series is chiefly determined by borings, from shafts, and by structural relations. The production of coal in the state has steadily increased since 1873, the product in 1907 being 48,091,583 short tons.

C. J. H.

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A Severe Test for the Memory

Amusing for all but exceedingly useful for liars

MACKLIN, the celebrated actor, one ... made "The Cultivation of the Memory" the subject of a ... which he said that to such perfection had he brou... anything by rote on once hearing it. Foo... and handed up the following sentences, desiring tha... them once and repeat them from memory:

> "So she went into the garden to cut a cabbage-leaf, to make an apple-pie; and at the same time a great she-bear, coming up the street, pops its head into the shop. 'What! No Pears Soap?' So he died, and she very imprudently married the barber; and there were present the Picninnies, and the Joblilies, and the Garcelies, and the Grand Panjandrum himself, with the little round button at top; and they all fell to playing the game of catch as catch can, till the gunpowder ran out at the heels of their boots."

It is needless to say that Foote had the laugh of old Macklin, and that Pears' Soap is matchless for the Complexion

OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

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CONDITIONS GOVERNING THE EVOLUTION AND DISTRIBUTION OF TERTIARY FAUNAS

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XI[1]

The subject allotted me being "The Conditions Governing the Evolution and Distribution of Tertiary Faunas," I may begin by stating certain propositions which, for the purposes of this discourse, may be assumed as axiomatic.

1. A fauna is an assemblage of organic species populating a given area at one and the same epoch, and—allowances being made for the preferences of such minor groups as carnivorous, phytophagous, littoral, benthal, petricoline, and limicoline animals—having for the most part identical geographical distribution.

2. We may regard it as indisputable that the properties of the environment shown to influence a living fauna, or to control its distribution, were capable in Tertiary[2] times of exerting an analogous influence on faunas now known chiefly by their fossil remains; and, conversely, if in a fossil fauna we are able to trace certain definite features, which in a living assembly would result from a particular environment, we are justified in concluding that the fossil fauna in

[1] Dr. F. H. Knowlton's article on "Succession and Range of Mesozoic and Tertiary Floras," which should have appeared as No. X in this series, has never reached the *Journal of Geology* and does not appear, therefore in its proper place. Should the article be submitted later, it will be published.

[2] The author realizes that these factors may not be entirely applicable to the faunas of pre-Tertiary epochs.

question was, when living, subject to the action of an analogous environment.

To illustrate this second proposition it may be said that if fig trees can now flourish and reproduce their species only in regions having a mean minimum temperature of thirty degrees Fahrenheit, and a summer mean temperature of not less than sixty degrees; and, secondly, if we find in the Tertiary leaf-beds of Greenland and Spitsbergen indications of groves of fig trees having flourished there in the Oligocene epoch; then we are likewise justified in assuming that in Greenland at that epoch the summer mean temperature did not fall far below sixty degrees, nor the winter cold maintain itself greatly below the minimum above mentioned.

Among marine animals a consensus of the evidence on record points insistently to temperature as the most important factor in determining the existence and persistence of species in a given area; and the toleration oi an organism and its progeny for fluctuations of temperature limits its geographical distribution as positively as would a material barrier. In the absence of such mortal extremes of temperature, material barriers, unless hermetically complete, really count for very little in determining distribution.

In utilizing fossil faunas as chronologic indicators of geologic time, the marine faunas are more readily utilized for the grand divisions of the scale than the land faunas, especially when the latter are characterized chiefly by fossil vertebrates. This is because the marine conditions are more uniform, less affected by meteorologic factors, and more dependent upon conditions which affect the whole hydrosphere rather than small areas of it. The struggle for life is less intense, the food supply generally more adequate, enemies less vigorous, and dangerous fluctuations of temperature far less frequent, in the sea than on land.

The same features make the land faunas more clearly indicative of minor divisions of the scale, and of the progress of organic evolution in the general region concerned; while less conclusive as to the contemporaneity of widely separated though analogous faunas.

The liability to sudden extermination by epidemic diseases, or by sharp meteorologic changes of very short duration, or even by the incursion of multitudes of small enemies, insects, or carnivora injuri-

ous to the young, is vastly greater among the land vertebrates than among marine animals. Marine vertebrates are more subject to injury from temporary causes than are the invertebrates associated with them. A marked instance of this was the destruction of the "tilefish" of the middle Atlantic coast a quarter of a century ago, if the explanation finally accepted as most probable by Professor Baird and other experts be the true one. The "tilefish" inhabited a region where the water, warmed by the proximity of the Gulf Stream, was of a moderate temperature. The combination of violent winds from a quarter which led to the forcing to the eastward of the Gulf Stream water, and to the influx of much colder water from the Polar current into the area thus vacated, was believed to be responsible for the almost total extermination of these fishes, which were found floating dead and apparently uninjured in millions on the surface of the sea, by navigators bound into New York and adjacent ports.

This temperature change which lasted at most for a few weeks would probably have had no effect whatever on the adult larger invertebrates of the same area, though to any of their larval young it might well have proved fatal. Another season would replace these, but the restocking of the fauna with "tilefish," which finally took place, required many years.

A statement of the factors which are regarded as modifying existing marine invertebrate faunas will put the student in possession of the chief factors which may have affected analogous faunas during past geologic time. My point of view is that afforded by a knowledge of conditions affecting molluscan life.

Census of species.—From a discussion too long to quote here in full,[1] I have drawn the following conclusions: That the part of the average mollusk-fauna which is capable of leaving traces in the shape of fossils, under conditions not greatly differing from those of the present day, in a region where the temperature of the sea ranges during the coldest winter month between 32° and 40° F. (which might be called *boreal*), would comprise about 250 species. In case the temperature ranged between 40° and 60° (*cool temperate*) about

[1] *Bull: U. S. Geological Survey, No. 84*, Correlation Papers, Neocene, 1892, pp. 25–28.

400 species might be expected. With a range between 60° and 70° (*warm temperate*) we should find about 500 species, and in the *tropical* zone (70° to 80° F.) not less than 600 species; and in specially favorable localities of the tropics nearly twice as many.

Learning from the characteristic genera what zone of temperature a given fauna may have belonged to, we can with confidence predict approximately the number of species which it will prove to contain when fully explored. Of course in a single locality where the characteristic situs is exclusively mud, or rock, or fine sand, only a certain proportion of the total fauna will be represented, but these minor groups are not entitled to the designation of a fauna as used in this paper.

Relations of temperature to the fauna.—In considering the relations of temperature of the water to the fauna, account must be taken of the vertical differences. The temperature of the water at the surface differs materially from that at the bottom in most regions, where the depth is over a few fathoms. Arctic or Antarctic species may extend in cold depths of ocean for thousands of miles; while, in the warm superficial strata above them and inshore from them, a totally different assembly lives and thrives. It is easy, in the case of widely diffused northern species, when deep water dredgings have revealed the distribution, to observe in the tables the boreal forms descending with the temperatures to deeper and deeper water as they approach the tropics. That this is so generally true is satisfactory evidence that the factor of pressure, being equalized by thorough permeation of the organism, is less effective in limiting distribution than most other factors. It seems incredible that the large eggs of abyssal mollusks can go through the processes of development under a pressure of tons to the square inch; since there must be a limit somewhere to the permeability of tissues. Still it is evident that they do.

Why temperature should be so important in limiting distribution is a question which may be answered in several ways. Brooks has shown that, while the embryonic oysters (*Ostrea virginica*) are swimming at the surface of the sea, an entire brood may be destroyed to the last individual, by a fall in temperature of a few degrees, due to a cold rain. While it is not improbable that oysters from the northern part of the range of the species, say Nova Scotia, may have in the embry-

onic state a greater tolerance for a fall in temperature than those of a relatively warmer region like Chesapeake Bay or the coast of Florida, yet it seems likely that a certain narrow range of temperature is required for the developmental stages, and that the distribution of the species is limited to the area where such temperatures may be had during the spawning season.

Thus, for example, young Chesapeake oysters of an inch and a half in breadth may be transported to the Pacific coast, planted in suitable locations, and will flourish well, growing even faster than in their native waters. Yet of the billions of spat which these oysters have discharged into the waters of the Pacific (fifteen or twenty degrees colder than the Chesapeake at spawning time) there is not a trace left in the shape of young oysters. In spite of the best efforts of the local oystermen the Chesapeake oyster has not become acclimated.

Another way in which temperature may affect a fauna is in promoting or inhibiting the minute plant-life which forms the food of many bivalves. In all cases it is certain that a fall below a certain level of temperature is more effective upon the animals subjected to it than a corresponding rise in temperature. The first, as I have indicated, may kill; the second, merely accelerate development.

The very low temperatures nearly universal on the floor of the open ocean, and the otherwise uniform conditions that prevail there, offer favorable opportunities for wide distribution of boreal organisms. I am informed by Mr. A. H. Clark that the Antarctic Crinoidea, characterized by scaly segments, have penetrated by this road in the Eastern Pacific even to the Oregonian region; while on the opposite coast the smooth-segmented Arctic forms have been traced far to the southward.

As indicators of subaerial conditions it is obvious that littoral invertebrates are more useful than those of deeper waters, since they are more exposed to climatic changes. It may happen that a vertical section of the submarine continental slope drawn at right angles to the coast from the shore to the oceanic floor may, and in most cases will, cut through a series of different faunas corresponding to the temperatures encountered. Off Cape Hatteras the cold inshore current from the north is the haunt of a cool-temperate fauna with

some boreal elements. Thirty miles off shore, in less than fifty fathoms, the fringe of the Gulf Stream protects a fauna in large part identical with that which characterizes the Bahama Banks and Bermuda. The large species of Venus, which penetrated to the north shore of the Gulf of Mexico with the cool Miocene water, have maintained themselves notwithstanding the subsequent rise of temperature and persist in these new conditions to the present day, a notable example of adaptation. On the other hand the subtropical Rangia and Corbicula, which advanced with the warm Pliocene waters far to the north of their original station, have left only sparsely scattered fossils as an indication of their invasion.

In the later Tertiaries the proportion of recent species is sufficient, taking into account the present distribution of these species, to afford the means for a very probable estimate of the temperature which prevailed during the particular portion of Tertiary time when they formed part of the fauna. An interesting example of this is afforded by a small collection of fossils obtained by Stimpson in 1865, from above the lignitic coal measures in the northeast angle of the Okhotsk Sea, in Penjinsk Gulf.[1] I have reported in full upon these fossils, and it is sufficient to say on this occasion that the climate and recent fauna of the locality are Arctic and the open water of the sea persists only for some three months of the year, while the species of fossils indicate that during their existence in the living state the annual mean air temperature, at the most moderate estimate, must have been 30° to 40° F. warmer than at present. Another instance has recently been brought to my attention. During the two seasons just past, collections have been made from the Pliocene auriferous gravels of the coast of Alaska near the town of Nome.[2] Thirty-three species have been identified of which seven appear to be new, eleven are now known living only south of the line of floating ice in winter, one is a Miocene species, and the remaining fourteen are common to the Alaskan fauna in general from the Arctic to British Columbia. This

[1] *Proc. U. S. Nat. Mus.*, Vol. XVI, No. 946, 1893, pp. 471–78, pl. LVI. The age of the fossil shells in the report upon these fossils was given as Miocene, but it is probable that like the analogous lignite deposits of the adjacent shores of America, the underlying coal measures may be referable to the Upper Eocene or Oligocene and may have been laid down contemporaneously with the American Kenai formation.

[2] Cf. *Am. Jour. Science*, Vol. XXIII, June, 1907, pp. 457, 458.

indicates clearly that during the Pliocene, when these gravels were being laid down, the climate of Norton Sound, now subarctic, was not colder than that of North Japan or the Aleutian Islands where the sea remains unfrozen throughout the entire year. This agrees well with the evidence from the marine Pliocene of the northeastern corner of Iceland, which has afforded over one hundred species, of which seventy-four are said to be common to the Crag fauna of the British Islands, corresponding to an annual mean air temperature not lower than 42° F., while it is hardly necessary to say that the present conditions in north Iceland are purely Arctic. A little patch of Pliocene at Gay Head, Mass., afforded a fragment of the genus Corbicula, now warm temperate in its distribution; while the older of the deposits at Sankoty Head, Nantucket, as well as those at Nome, show that some of the species which ranged at that period from Bering Sea to the North Atlantic are now strictly confined to temperate waters in their respective hemispheres.

I have given most of my time to the relations of temperature to faunas, as this is the most important, pervasive, and obvious factor of the modifying environment, but there are a few others which may be briefly alluded to.

The question of food is next in importance to temperature. It is true that the ocean almost everywhere is a generous provider for its inhabitants, so that only special scrutiny reveals important differences in the food supply, a large part of which is furnished by almost microscopic animals. Yet it has been conclusively shown that in places where a persistent movement brings constantly fresh supplies of food and well-aerated water, as on the continental slope washed by the Gulf Stream, or where the periodical ebb and flow of the tides do the same thing on a smaller scale—there the oceanic population flourishes with especial vigor and abundance. Near the shores a special quota of plant-feeders live, in their turn furnishing provender for carnivorous species. The distribution of plant food in the shape of algae thus governs the distribution of the phytophagous species. We find on the basalts, andesites, and recent lavas of the Aleutian chain of islands, enormous groves of kelp and meadows of olivaceous rock-weed. Whether because of something in the chemical composition of these rocks, or otherwise, the red and green seaweeds are

almost wholly absent from them. However, where the granitic masses which form the core of some of the islands (and in other places stand alone, domelike in the sea) are within reach of the waves, we find a special flora of the more bright-colored algae and a special fauna dependent upon them. No matter how isolated the patch of granite, the characteristic animals recur, and in many cases reproduce in their own tints the rosy hue of the plants upon which they depend for food.

In the abysses where the absence of sunlight excludes plant life the animals are almost exclusively carnivorous and largely subsist on the abundant rain of dead organisms which slowly descends from the surface layers of the sea.

It has been customary to regard the 100-fathom line as constituting a sort of boundary between the fauna of the shores and of the deeps. This has a certain foundation in the fact that at greater depths no living algae can exist for want of sunlight. A more or less constant migration, casual or accidental, is constantly taking place between the littoral region and the deeps, but it is so slow, and the process of adaptation to the new conditions so gradual, that we may safely regard the abyssal fauna as even geologically old. I have called attention to certain features of the eastern Pacific and Antillean abyssal faunas which illustrate these remarks in the introduction to a recent monograph.[1]

Freshwater and terrestrial invertebrates are subject not infrequently to one set of influences which is rarely noticed in the open sea. This is, in the case of the limnophilous species, a change in the mineral content of the water in which they live. This is usually gradual and when injurious chiefly due to the concentration of salts (which exist in all freshwaters arising from drainage) by evaporation. In the case of many large Pleistocene lakes, of which the prehistoric Lake Bonneville may be taken as an example, this process has been carried on until the saline content of the water became so excessive that all molluscan life became extinct, as in the Great Salt Lake of Utah. A careful study of the beds of shell-marl deposited by the shrinking lake shows that the effect of the gradually increasing salinity of the water on the freshwater mollusks contained in it was

[1] *Bull. Mus. Comp. Zoölogy*, Vol. XLIII, No. 6, October, 1908, pp. 205–12.

to lead to a thickening and corrugation of the shell, a tendency to longitudinal ribbing, and a diminution in average size, all of which changes may perhaps be due directly to the astringent action of the salts of sodium and magnesium upon the thin and delicate margin of the mantle which secretes the additions to the shell. These characteristics become more and more pronounced as the waters become more saline, until finally the conditions become too rigorous for survival. The gradually intensified effect of the increase of salinity may be beautifully illustrated by a collection of the fossil shells from the successive marl beds around Great Salt Lake. Another instance, probably of the same nature, is afforded by the marls of Steinheim, in Wurtemburg, of which the mutations shown by the species of Planorbis, in particular, are described in the well-known monograph by Hyatt.[1]

A somewhat similar effect seems to be produced in the case of landshells inhabiting arid volcanic islands in windy regions. Here the astringent effect appears to be produced by the alkaline volcanic dust to which these animals living on almost bare shrubs or among sparse herbage are more or less constantly exposed. I have called attention to the conditions under which this effect seems to be produced in a paper on the landshell fauna of the Galapagos Islands.[2] This illustrates how upon animals of quite different systematic relations, similar effects, simulating an apparent convergence, may be caused by the direct action of the environment upon individuals. Paleontologically these instances are worth noting, as otherwise the forms concerned might well be regarded as belonging to totally different groups from the individuals which developed normally in an ordinary habitat.

In conclusion I may call attention to certain factors which have serious importance in modifying the fauna of a large extent of coast catastrophically, and which inferentially are to some extent responsible for the marked changes we observe in different stratigraphic horizons where we do not find indications of coincident orogenic changes.

[1] "Genesis of the Tertiary Species of Planorbis at Steinheim," *Anniv. Mem. Boston Soc. Nat. History*, 1880, pp. 114, pls. I–IX, 4to.

[2] "Insular Landshell Faunas, Especially as Illustrated by the collection of Dr. G. Baur on the Galapagos Islands," *Proc. Acad. Nat. Sciences, Philadelphia*, August, 1896, pp. 395–459.

In some regions, as the west coast of the Floridian peninsula, the strata may be slightly inclined so that the beds between which subterranean waters move have their edges beneath the sea. Torrential rains in the interior of the peninsula carry vegetable matter into the interstices of the soft limestone rocks, where it decays with the accompanying production of carbon dioxide and sulphuretted hydrogen gas. This accumulates and under the hydrostatic pressure of an exceptionally heavy rainfall is sometimes forced out beneath the sea from the edges of the submerged strata in sufficient volume to kill by suffocation every living thing along many miles of coast. This has happened on the coast of Florida several times within my recollection. The repopulation of the devastated area is slow and can rarely reproduce exactly the same assemblage of animals which previously occupied that area.

Another mode in which widespread extermination of a sedentary population of invertebrates may be brought about is by the sudden appearance of vast multitudes of minute organisms like *Peredinia*. Within the last few years, both on the coasts of Japan and of California, the sea at times has been covered for miles with reddish clouds of these submicroscopic creatures. On their advent near the shore, driven by wind or currents, the shellfish, corals, and fishes are rapidly suffocated, and, if the pest continues, everything within the area it occupies will succumb. I have heard that, within two years, the Japanese pearlshell preserves on the seashore of that country have been almost wholly ruined by the organisms referred to, with the loss of hundreds of thousands of dollars, to say nothing of years of labor rendered fruitless.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

13. EOCENE-OLIGOCENE NORTH AMERICA

The Eocene-Oligocene aspect of North America differed from the Cretaceous and resembled the present. The east and west were united. The Cordillera had begun its development as a system of many mountain chains, most, if not all, of which are represented in existing ranges; yet few, if any, of which have had an uninterrupted growth. They became high in the Eocene, but were greatly eroded in the Oligocene and Miocene. The volcanic activity which marks the Cordillera was very notable during the Eocene. The eastern part of the continent remained low.

By erosion of the mountains and by contributions from the volcanoes great thicknesses of sediment accumulated in interior basins of the Cordillera. The deposits were in part fluviatile, in part eolian, in minor part lacustrine. On the map their distribution is shown by the ruling for continental deposits in the central west.

In the Gulf region and also in Alaska extensive low lands and favorable climate produced extensive marshes which are now represented by coal beds and are also indicated by the vertical ruling.

The continental connections of North America during the Eocene and Oligocene appear to have been established and interrupted, as is shown by the relations of land animals. Osborn infers that there was intermigration with Europe during the Wasatch epoch,[2] and thenceforward separation from Europe until the Oligocene, when faunistic reunion took place. These inferences are suggested on the map by the temporary lands linking Alaska with Siberia and Greenland with England.

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Osborn, H. F., "Cenozoic Mammal Horizons of Western North America," *U. S. Geological Survey Bull. 361*, 1909.

EOCENE - OLIGOCENE
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS

The region of the West Indies was the seat of an embayment of the Atlantic, beneath which was deposited the widespread Oligocene limestone, characterized by the fauna of a warm oceanic current. This fauna spread north along the southeastern coast of the United States.

I am indebted to Dr. Wm. H. Dall and Dr. Ralph Arnold for discussion of the distribution of marine faunas and their relation to inferred currents.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

14. MIOCENE NORTH AMERICA

In outline, North America during the Miocene resembled the continent during the Eocene. The surface was, however, less mountainous. The sites of the Sierra Nevada and of the Coast Range of British Columbia were plains or low hilly lands. The Rocky Mountains of the United States were comparatively low. In British Columbia, and thence southward through Washington, Oregon, and Nevada occurred outflows of lava, which covered many thousand square miles, but which in general were not from volcanoes. Though probably subordinate in volume of lava erupted, volcanoes were numerous and they gave off quantities of volcanic ash, which formed deposits in lakes, particularly in western Montana and British Columbia.

The elevation of the Rocky Mountains of western Montana and British Columbia by overthrust, and subsequently the development of longitudinal valleys and separate ranges by vertical displacements, probably began in the Miocene period and may have culminated during Pliocene or early Quaternary time.

In the West Indian region the close of the Oligocene period was marked by a notable disturbance, which raised a folded mountain chain from Puerto Rico to Cuba and probably continuously to Yucatan. It may also have closed the Isthmus of Tehuantepec and possibly have temporarily connected Honduras with South America. Another possible line of connection is around the eastern end of the Caribbean through the Windward Islands. If, however, such a land link united North and South America it was but temporary.

The effect of the Cuban elevation, or of some other geographic

[1] Published by permission of the Director of the U. S. Geological Survey.


MIOCENE
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
TEMPORARY LAND
MARINE CURRENTS POLAR
EQUATORIAL
CONTINENTAL DEPOSITS, SOMETIMES
INCLUDING MARINE SEDIMENTS

change not yet suggested, was to shut off from the northern Gulf and southern Atlantic coasts the warm currents which had sustained a rich southern fauna and to admit the cool northern waters with their appropriate life. A very pronounced faunal change, without any marked stratigraphic break in the sediments, was the result.

ENVIRONMENT OF THE TERTIARY FAUNAS OF THE PACIFIC COAST OF THE UNITED STATES*†

RALPH ARNOLD

XII

* Published with the permission of the Director, U. S. Geological Survey.

† Read before the Geological Society of America at the Baltimore meeting, December 29, 1908.

INTRODUCTION

This paper was presented as part of the symposium on "Correlation" arranged by Mr. Bailey Willis as the principal subject for discussion in Section E of the American Association for the Advancement of Science, and later continued as the main feature of a special section of the Geological Society of America, at Baltimore during Convocation Week, 1908. The paper treats in a general way of the character and distribution of the sediments laid down, and the faunas and the conditions prevailing during the Tertiary period on the Pacific Coast of North America, more especially that portion lying between Puget Sound on the north and the Gulf of California on the south. The discussion is also restricted almost exclusively to the territory directly affected by the sea, as a detailed consideration of the conditions and faunas prevailing inland belongs more properly within the province of the paleobotanist and vertebrate paleontologist. Special attention is called at several places throughout the discussion to the extraordinary localization of many of the earth-movements affecting the region under discussion and the writer wishes to advance this localization of phenomena as an argument against the too free use of diastrophism, unsupported by paleontologic evidence, as a basis of correlation.

The preparation of the paper has necessitated the correlation of the various Tertiary formations of the Pacific Coast—in fact the paper is obviously based on these correlations—and for that reason a general table of correlation is here included for reference. Lack of space prevents a discussion of the reasons for many of these correlations. Some of them differ from those previously published by the writer,[1] but for the most part they are those usually accepted by West American geologists and paleontologists.

[1] *Jour. Geol.*, Vol. X, 1902, p. 137; *Mem. Cal. Acad. Sci.*, Vol. III, 1903, p. 13; *U. S. Geological Survey Prof. Paper 47*, 1906, p. 10; *U. S. Geol. Survey Bull. 309*, 1907, p. 143; *ibid., 321*, 1907, p. 21; *ibid., 322*, 1908, p. 27.

The fourfold subdivision of the Tertiary is the one which seems best to fit the phenomena of the Pacific Coast, although for convenience of discussion in the present paper the writer has separated the upper from the lower Miocene on account of the diverse geologic histories of the two. It is obviously impossible to make exact correlations between the European and East American subdivisions on the one hand and the faunal and stratigraphic subdivisions of the Pacific Coast on the other, but by means of various direct and indirect methods it is possible, however, to make approximate correlations, and as the work progresses these approximations will be made to approach nearer and nearer to the exact. Paleontology forms the basis for the correlations, but other criteria, such as periods of widespread diastrophism and volcanic activity and profound changes in climate, have also been taken into consideration. It is well to mention here that the total thickness of Tertiary and Quaternary sediments in California approximates 25,000 feet and that within the Tertiary and Quaternary periods, relatively short, geologically speaking, as compared with the earlier divisions of the time scale, probably more distinct and profound movements have taken place on the western border of our continent than have occurred over an equal length of time in any of the preceding periods within the limits of North America.

Five maps have been prepared to elucidate the paper, each respectively representing the supposed distribution of land and water along the western border of the United States during the Eocene, the Oligocene, the lower Miocene, the upper Miocene, and the Pliocene and Pleistocene epochs. It is admitted that these maps are composites; that is, they represent the distribution not at any definite moment but throughout a period of time during which the local conditions usually changed but little relative to the changes taking place between these periods. For instance, the areas shown as subject to deposition during the Eocene are the areas over which deposits were laid down at one time or another during the Eocene epoch. In the case of certain portions of Puget Sound and elsewhere, marine conditions prevailed during the early Eocene, brackish-water conditions a little later, and freshwater or river, and coal-marsh conditions toward the close. In other portions of the same general area the conditions

alternated. It is obvious, therefore, that the legends on the maps are very general. Only in those instances where the body of water indicated as fresh remained fresh throughout practically the whole of its existence is it indicated as a freshwater area on the map.

The periods chosen for representation and as units for discussion are neither of equal length nor of equal importance, and the lines separating them are in some instances arbitrary; but it is believed that they serve the purpose of systematizing the discussion better than any other plan of subdivision. The data are incomplete and the conclusions admittedly tentative, and it is expected that future investigations will disclose new and important information, which will necessitate alterations, but the fact remains that general reports of this kind, based as they are on the present state of our knowledge, often point the way to more exact results in the future.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Messrs. Bailey Willis, J. S. Diller, T. W. Stanton, Robert Anderson, Chester W. Washburne, and several others for personal assistance in the preparation of the text and maps, and to express his thanks for the services rendered. In addition to the personal aid received, the literature relating to the subject of West Coast geology has been freely drawn on in the compilation of relevant data and in many cases proper acknowledgment for this is made in the text.

THE EOCENE PERIOD

RELATION OF THE EOCENE TO THE CRETACEOUS

Before entering into the details of the geologic history of the Tertiary it is well to consider for a moment the relations existing between the earliest Tertiary rocks and those of the Cretaceous, and to note the conditions initiating the Tertiary, as implied by these relations.

A widespread unconformity exists between the Eocene and the Cretaceous on the Pacific Coast of North America. Throughout Washington, Oregon, and certain parts of California, this unconformity is angular, while over considerable areas in California and at one locality in Oregon the unconformity may only be recognized by a more or less marked hiatus in the faunas.

It is a noteworthy fact that with one exception wherever the line between the marine Eocene formations (Martinez, Arago, Tejon, etc.) and the Cretaceous beds is marked by an angular unconformity, the underlying beds are either of lower Cretaceous (Knoxville) or middle Cretaceous (Horsetown) age, and that wherever the Eocene rests on the Chico, or upper Cretaceous, excluding the case at San Diego, the unconformity is not angular, and as far as the stratigraphic evidence goes, the two formations represent an apparently uninterrupted period of sedimentation.

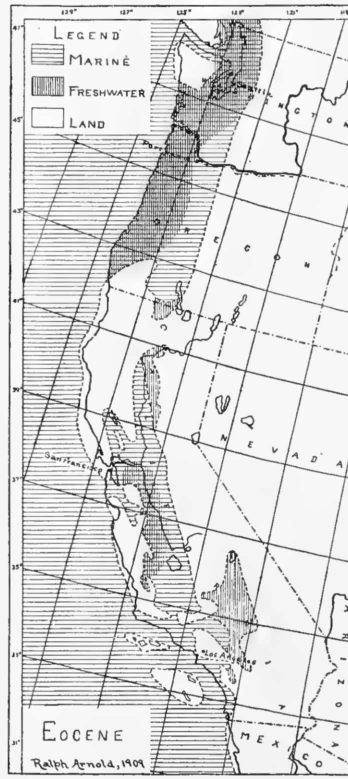

FIG. 1.—Map showing hypothetical distribution of land and water on the Pacific Coast of the United States during Eocene time.

The apparent conformability of the Eocene on the Cretaceous, together with the superficial similarity of their faunas, led Gabb and Whitney of the early California Survey to class the Martinez and Tejon formations with the Cretaceous. White, Stanton, and Merriam have, however, shown the Eocene age of the Martinez and Tejon. Of the relationships existing between these two and the Chico, or upper Cretaceous, Dr. Merriam has the following to say:

> The Martinez group, comprising in the typical locality between one and two thousand feet of sandstones, shales, and glauconic sands, forms the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty species, of which the greater portion is peculiar to itself. A number of its species range up into the Tejon and a very few long-lived forms are known to occur also in the Chico. Since the Martinez and Chico are faunally only distantly related it is probable that an unconformity exists between them.[1]

[1] *Jour. Geol.*, Vol. V, 1897, p. 775.

Another fact showing the relations existing between the Eocene and the Cretaceous is the occurrence in the Eocene beds in the Roseburg region, Ore., of oysters so similar in appearance to the characteristic Cretaceous fossil, Gryphæa, that without their accompanying Eocene fauna these oysters would certainly be mistaken for Cretaceous forms.

CONDITIONS IMMEDIATELY PRECEDING AND INAUGURATING THE EOCENE

Immediately preceding the Eocene period practically all of Washington, all of Oregon excepting a small area along its southern border, the Sierran and desert region, and certain portions of the coastal belt of California were dry land. Most areas in California, and possibly also those in the Puget Sound region, which were occupied by the Chico or upper Cretaceous sea, were still under water, or at least elevated only slightly above sea-level and this without deformation of the Chico beds or subsequent erosion before subsidence. Influences, however, which markedly affected the faunas without materially influencing the sedimentation, were actively at work, and it seems likely that these influences were due to worldwide climatic changes augmented by a readjustment of ocean currents following orogenic movements. In Washington, according to G. O. Smith,

> the deposition of the Cretaceous rocks seems to have been followed by an epoch in which they and older rocks were folded and uplifted. Thus was an early Cascade Range outlined, although it may be that the range had an even earlier origin. Accompanying the post-Cretaceous mountain growth were intrusions of granitic and other igneous rocks which now constitute a large part of the northern Cascades. During the time that any portion of this area was not covered by water the rocks were exposed to the vigorous attacks of atmospheric agencies. Thus, at the beginning of the Tertiary the northern Cascade region appears to have been a comparatively rugged country, although not necessarily at a great elevation above sea-level.[1]

A study of the interrelations of the Cretaceous and Eocene formations outlined in a preceding section clearly indicates that any important pre-Eocene mountain-building movements affecting the Cretaceous rocks in the California province must have taken place before the deposition of the Chico or upper Cretaceous sediments. As shown by F. M. Anderson,[2] the movements immediately preceding

[1] "Ellensburg Folio," *Geol. Atlas U. S., No. 36*, p. 1.

[2] *Proc. Cal. Acad. Sci.*, 3d ser., "Geology," Vol. II, 1902, p. 53.

the deposition of the Chico were accompanied by basic igneous intrusions. No profound movements and no volcanic activity accompanied the post-Chico (post-Cretaceous) movements in California as they did in Washington.

Steep mountains bordered the youthful Eocene sea in southern Oregon, northeastern California, and north of San Diego, and occupied portions of one or more large islands in the region of Monterey and Santa Barbara counties south of San Francisco. Elsewhere the relief of the land appears to have been comparatively low and the shore-lines with few bays or estuaries.

DISTRIBUTION AND CHARACTER OF SEDIMENTS

Rocks of marine origin and Eocene age are found at many localities throughout Washington and Oregon west of the Cascade Range, and over considerable areas of the Coast Ranges in central and southern California. Although Eocene rocks probably once fringed the greater part of the western base of the Sierra Nevada, they are now all removed by erosion or covered by later formations except at one locality near Merced Falls. For the most part the Eocene rocks of the Pacific Coast are either sandstone or shale. Conglomerate is found at the base of the formation throughout southeastern Oregon, north of San Diego, and at a few localities along the northeastern flanks of the Coast Range; and at Port Crescent, Washington, Eocene fossils are associated with tuff; but these occurrences are exceptional. Also, diatomaceous shales occur at the top of the Eocene series in the vicinity of Coalinga, Cal., where they are believed to be the source of important deposits of petroleum. Coal and other indications of shallow- and brackish-water conditions are found over much of Washington and Oregon and California, usually overlying marine Eocene beds. The maximum thickness of the Eocene sediments varies from 8,500 feet east of the Cascades,[1] 10,000 to 12,000 feet in western Oregon[2] to 9000± feet in southern California.[3]

CONDITIONS PREVAILING DURING THE EOCENE

During the early part of the Eocene, marine conditions prevailed over a considerable territory that later was covered by brackish- or

[1] G. O. Smith, *Mt. Stewart Folio.*

[2] J. S. Diller, *Roseburg, Coos Bay, and Port Orford Folios.*

[3] Ralph Arnold, *U. S. Geol. Surv. Bull. 321*, p. 21.

freshwater or swamp conditions. The regions thus affected include a large part if not all of the Puget Sound and western Oregon provinces and a considerable part of central California. How far these conditions extended eastward into central Washington and Oregon it is not possible to state owing to the covering of the Eocene by later volcanic flows. It is quite possible, however, that certain portions of the Sound country was at no time submerged under salt water, or if at all only for very short periods, for Willis states[1] that coal occurs both in the basal and upper portions of the Puget formation, which is believed to cover the period from the Eocene into the Miocene. He states further that "the physical history which is recorded in the Puget formation is one of persistent but frequently interrupted subsidence" in which "the alternation of coal beds with deposits of fine shale and coarse sandstone indicates that during this great subsidence the depth of water frequently changed." He infers "that at times the subsidence proceeded more rapidly, and that the deepened water was then filled with sediment, until the tide-swept flats became marshes, and for a time vegetation flourished vigorously in the moist lowlands," this rotation being repeated intermittently. This description of conditions is believed also to apply to much of Alaska, western Oregon, and portions of the interior valley of central California during the later Eocene. The epicontinental Eocene seas were for the most part rather shallow and in the later Eocene particularly were bordered by wide tide flats and marshes.

In the region of Lower Lake in Lake County, Cal., in the Mojave Desert immediately north of the Sierra Madre, and in the vicinity of San Diego, the early Eocene (Martinez) sea was present, but later receded and these particular areas are believed to have been dry land during the later Eocene. The Mojave Desert basin may have been covered with freshwater at this later period as lake deposits believed to be largely of Eocene age are known from the region contiguous to it. This would be in accordance with the conditions prevailing in eastern Oregon[2] and Washington[3] where great lakes existed during Eocene time immediately east of what is now the Cascade Range,

[1] *Tacoma Folio*, p. 2.

[2] J. C. Merriam, *Bull. Dept. Geol. Univ. of Cal.*, Vol. II, No. 9, p. 286, 1901.

[3] G. O. Smith, *Mount Stewart and Ellensburg Folios*, Washington.

and possibly also east of the Sierra Nevada. Erosion tending toward a base-leveling of the Sierra Nevada and other elevated portions of the Pacific Coast must have proceeded rapidly during the Eocene as is evidenced by the great thicknesses of strata laid down during the period and by the fact that high relief was not present during the Oligocene except in rare instances, although the Oligocene in general was a period of uplift for much of the Pacific Coast province.

OROGENIC MOVEMENTS AND VOLCANIC ACTIVITY IN THE EOCENE

After the deposition of the early Eocene came a period of temporary elevation, erosion, and great volcanic activity in Washington, Oregon, and northern California. Extensive basaltic eruptions through long conduits and over the eroded rock surfaces took place in eastern Washington and western Oregon, while in the region of the Olympic Mountains and eastern Oregon basalt flows and volcanic outbursts were also taking place. Eocene volcanic disturbances so pronounced in the north do not appear to have affected the Sierra Nevada nor the coastal region of California south of the Klamath Mountains.

CLIMATE DURING THE EOCENE

The faunas and floras of the Eocene indicate subtropical conditions for this period at least as far north as Puget Sound. The marine faunas of the Pacific Coast Eocene are closely allied to those of the Eocene of the southern states and the Eocene shells, *Corbicula*, for instance, as a rule belong to groups showing a predilection for warm waters. This supports the evidence offered by the floras which are of a decidedly tropical aspect. Doctor Knowlton has the following to say in connection with the flora of the Puget formation, which may be regarded as typical of the Washington, Oregon, and California Eocene:

> The lower beds [the Eocene portion of the Puget formation], on account of the abundance of ferns, gigantic palms, figs, and a number of genera now found in the West Indies and tropical South America, may be supposed to have enjoyed a much warmer, possibly a subtropical, temperature, while the presence of sumacs, chestnuts, birches, and sycamore in the upper beds [Oligocene and lower Miocene] would seem to indicate an approach to the conditions prevailing at the present day.[1]

[1] *Tacoma Folio*, p. 31.

THE OLIGOCENE PERIOD

THE OLIGOCENE A PERIOD OF ELEVATION

The Oligocene on the Pacific Coast was primarily a period of elevation and erosion over many areas which are now land. As indicated by the fine character of most of the sediment deposited during the period, the relief was not strong, except in a few regions. Outside the Washington-Oregon province there are few evidences of the period, except a more or less marked unconformity between the Eocene and lower Miocene, and these for the most part are on the extreme continental border or along the edges of the provinces of persistent subsidence. The extreme localization of the post-Eocene movements is well shown in the southwestern San Joaquin Valley where the lower Miocene and Eocene are apparently conformable and again occur within a distance of a quarter of a mile separated by a profound angular unconformity. Strata of undoubted Oligocene age consisting largely of sandy to clayey shales and carrying a characteristic marine fauna are found at many localities throughout the Puget Sound and northwestern Oregon areas and an isolated occurrence of similar beds is found in the Santa Cruz Mountains, a short distance south of San Francisco. Wherever their relations are known these beds lie conformable with the Eocene below and lower Miocene above; they therefore mark areas of persistent subsidence. A characteristic reddish to lavender formation (the Sespe), consisting of sandstone, shale, and some conglomerate found in Ventura and Los Angeles

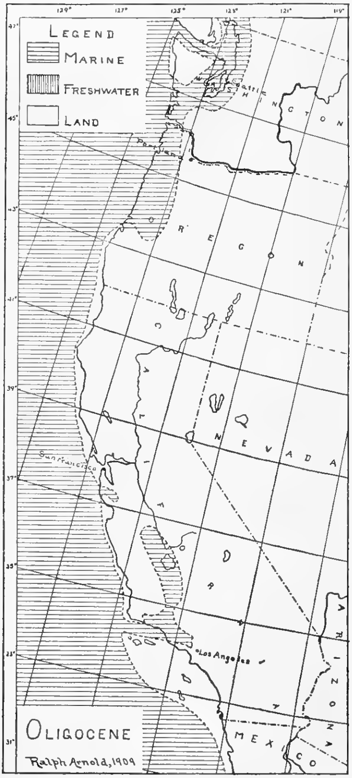

FIG. 2.—Map showing hypothetical distribution of land and water on the Pacific Coast during Oligocene time.

counties in southern California, has been doubtfully referred to the Oligocene and the map made to agree with this correlation; but it is possible this formation is Eocene.

Certain marine shales and sands underlying the lower Miocene beds in western Fresno and Kern County may also belong to the Oligocene. If so they imply that an arm of the sea remained in the San Joaquin Valley following the post-Eocene elevation that excluded marine conditions from much of the coastal belt of western America.

The total thickness of the Oligocene over the region where it has been recognized varies from over 1,000 feet in Washington to 2,300± feet in the Santa Cruz Mountains. The Sespe formation of Ventura and Santa Barbara counties, which has been tentatively correlated with the Oligocene, attains a maximum thickness of about 4,300 feet.

CONDITIONS OF EROSION AND DEPOSITION

With the close of the Arago stage (Eocene)[1] the Klamath Mountains and Coast Ranges of Oregon and California were uplifted to a moderate elevation and subjected to extensive erosion, in some localities completely removing the sediments deposited during the Eocene. With the possible exception of an area in Ventura County in southern California no mountains of strong relief contributed directly to the Oligocene sediments. In eastern Washington the great lakes which prevailed during the Eocene were elevated and the sediments which had been deposited in them were folded and eroded, the resulting detritus in addition to large quantities of volcanic ejectamenta being collected in bodies of freshwater in eastern Oregon farther south. It is thus known that with the elevation of this northern country volcanic activity still continued although on an insignificant scale as compared with the periods preceding and following the Oligocene. In California there is no evidence of volcanism in the Oligocene period.

FAUNA AND CLIMATE OF THE OLIGOCENE

What little is definitely known concerning the faunas of the Oligocene as a whole indicates their closer affiliation to the Miocene than to the Eocene. The fauna from the Oligocene of the Santa Cruz Mountains (San Lorenzo formation) and a similar fauna from

[1] J. S. Diller, *Roseburg Folio.*

Porter near Grays Harbor, in western Washington, are believed to be the oldest of the definitely known Oligocene. In these assemblages are several species showing distinct Eocene affinities; in the later Oligocene the forms are decidedly more closely allied to Miocene forms. The climatic conditions prevalent on the west coast of the United States during the Oligocene are believed to have been transitional from the subtropical of the Eocene to the more temperate of the lower Miocene.

THE LOWER MIOCENE PERIOD

CONDITIONS INAUGURATING THE LOWER MIOCENE

The Oligocene period of elevation and moderate erosion was followed by diastrophic movements of a most interesting and important character. It was during this post-Oligocene period of disturbance that definitely recognizable movements along what is now termed the great earthquake rift and associated rifts of California first took place. Although profound regional subsidence was the rule in central and portions of southern California, local movements along the faults mentioned elevated blocks of the pre-existing formations into islands, usually of considerable relief, in the region now occupied by the Coast Ranges. It is in a study of details such as the distribution of the land and water in these fault zones that composite maps, such as those accompanying this paper, become entirely inadequate and sometimes misleading. Suffice to say that beginning with the pre-Vaqueros (pre-lower Miocene) period of disturbance many of the major blocks within the general fault zone of the Coast Ranges, and to a lesser extent, the minor blocks within the major masses, were seldom at rest for more than relatively short periods up to the present day. Some folding took place during the pre-Vaqueros period, but it was local in character, such as that exhibited in the Coalinga district, and of minor importance as compared with the vertical movements of the large masses. One of the most significant facts in connection with the lower Miocene subsidence was the retention of its position above sea-level of the Sacramento Valley region at a time when the San Joaquin Valley to the south was subjected to marine conditions. This discordance of movement between the two ends of a continuous basin, which in the discussion of California

geology has heretofore been considered as a unit, is believed to be related to the positive or upward-tending forces accompanying or immediately preceding the important volcanic activity which took place during early Miocene[1] time adjacent to the Sacramento Valley, and northward into Washington, but which are absent or insignificant in the region contiguous to the San Joaquin. In this connection it is also worthy of note that the greater part of the Willamette Valley was also out of water during the lower Miocene.[2]

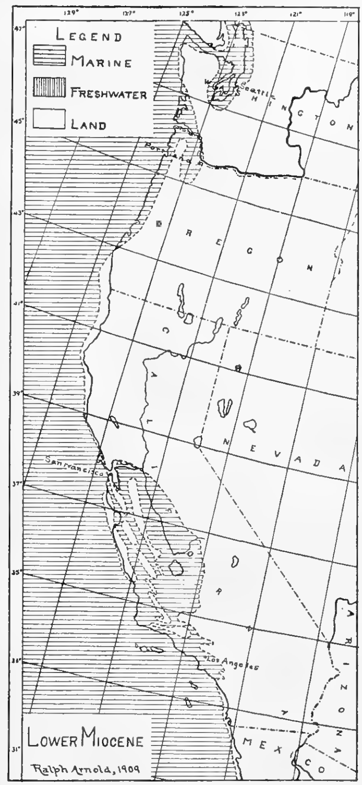

Fig. 3.—Map showing hypothetical distribution of land and water on the Pacific Coast during lower Miocene time.

DISTRIBUTION AND CHARACTER OF SEDIMENTS

The Vaqueros or lower Miocene proper, and the Monterey or lower middle Miocene epochs have been included in mapping and discussing the lower Miocene, for together they mark by subsidence the beginning of a new geologic cycle following the Oligocene elevation. Locally the Vaqueros and Monterey have totally unlike histories. The Vaqueros in the Coast Ranges of central California is characteristically conglomeratic at the base, and sandy, with minor quantities of shale, in its upper portion. In the northern part of southern California it is largely dark arenaceous shale associated with minor quantities of sandstone. The Monterey, on the other hand, is composed largely of diatomaceous material with minor quantities of sandstone, fine volcanic ejectamenta, and limestone, the last three

[1] J. C. Merriam, *Bull. Dept. Geol. Univ. Cal.*, Vol. V, p. 173.

[2] Oral communication from Mr. Chester W. Washburne.

usually more noticeable toward the base. The Modelo formation of Ventura County, the probable equivalent of the Monterey, contains two important coarse sandstone zones. In the region of Mount Diablo the Vaqueros and Monterey formations comprise alternations of sandstone and shale. In Washington and Oregon the whole lower Micoene is largely sandstone with some associated shale. A gradual gradation between the two formations is the rule, although their contact is often sharply marked and in some places is an angular unconformity.[1] The thickness of the Vaqueros is as much as 3,000 feet, that of the Monterey over 5,000 feet, a total for the whole of the lower half of the Miocene of over 8,000 feet.

CONDITIONS OF DEPOSITION

The deposition of the lower Miocene (Vaqueros) sediments was inaugurated over much of the submerged territory, along the shores of islands of sharp relief. Erosion and deposition were rapid within local basins, especially in the region from the Santa Cruz Mountains southward to San Luis Obispo County, and still there were localities within these areas of intense sedimentation where deposition was slow. It is the belief of the writer that these variations were dependent, at least in part, on the positions of the areas in question relative to the steep or low slopes of tilted fault blocks.

Over those portions of southern California, such for instance as in Ventura County, where the sea supposedly occupied the present land-area during the Oligocene, the conditions during the Vaqueros (lower Miocene) were quite different from those northward in the Coast Range archipelago. Instead of the littoral conditions accompanied by rapid and coarse sedimentation of the latter province there was in the Ventura County area deep water with slower deposition and finer sediments, especially in the earlier Miocene.

The lower middle Miocene (Monterey) shale formation is one of striking individuality, and conditions of unusual character prevailed during its period of deposition.[2] The land which had begun to subside at the beginning of Miocene time, later, at the inauguration of the middle Miocene, sank over a large part of the region of Cali-

[1] Branner, Newsom, and Arnold, *Santa Cruz Folio*.

[2] For a fuller description of the Monterey see A. C. Lawson and J. D. L. C. Posada, *Bull. Dept. Geol. Univ. Cal.*, Vol. I, pp. 22 ff.; H. W. Fairbanks, *ibid.*, Vol. II, pp. 9 ff.; Ralph Arnold and Robert Anderson, *U. S. Geol. Survey Bull. 322*, pp. 35 ff.

fornia now occupied by the Coast Ranges and fairly deep water conditions became prevalent. A large area embraced between the Salinas and San Joaquin valleys and extending northward from the Antelope and Cholame valleys well toward the Livermore Valley was an exception to this general subsidence, and although much of it had been under water in Vaqueros time it was probably dry land or at least an area not subject to sedimentation during the Monterey. The wearing-away of extended land-areas ceased as they became submerged, and the material for the formation of coarse detrital deposits was no longer plentiful. Although the total thickness of the Monterey approximates a mile it is not probable that the depth of the sea at any time was as much as this, being more likely closer to half a mile.

During the period of transition between the Vaqueros and the Monterey, limestone was formed chiefly, but somewhat inclosed basins where deposits of alkaline mud were laid down apparently existed in places. Such a basin is indicated by the alkaline gypsiferous clays on the south side of the Casmalia Hills, in northwestern Santa Barbara County, probably representing upper Vaqueros.

During the early part of the middle Miocene (Monterey) time conditions were variable, calcareous and siliceous deposits alternating, probably as a result of alternating temporary predominance in the sea of organisms with calcareous or siliceous shells. As the period progressed the siliceous organisms became more predominant and remained so, making up a large fraction of the total bulk of the Monterey formation. It was an age of diatoms. These small marine plants lived in extreme abundance in the sea and fell in showers with their siliceous tests to add to the accumulating ooze of the ocean bottom, just as they are forming ooze at the present day in some oceanic waters. It is well known that diatoms multiply with extreme rapidity. It has been calculated that, starting with a single individual, the offspring may number 1,000,000 within a month. One can conceive that under very favorable life conditions, such as must have existed, the diatom frustules may have accumulated rapidly at the sea bottom and aided the fine siliceous and argillaceous sediments in the quick building-up of the thick deposits of middle Miocene time, some of which are a mile through. These diatomaceous shales are the source of some of the richest petroleum deposits of California.

VOLCANIC ACTIVITY IN THE LOWER MIOCENE

The most important display of volcanic phenomena on the Pacific Coast took place during the early and middle Miocene, and probably reached its climax at the time of the widespread post-early middle Miocene (post-Monterey) disturbances. Great volcanoes were active throughout eastern Washington and Oregon and in the Coast Ranges of California from the Santa Cruz Mountains at least as far south as the Santa Ana Mountains in Orange County. The lavas and tuffs emitted by these volcanoes, and the associated intrusions, were basic in character. Certain facies of the Monterey are believed by Lawson and Posada[1] to consist of fine volcanic ash ejected from distant volcanoes of the period.

FAUNAS AND CLIMATE OF THE LOWER MIOCENE

The marine faunas of the lower Miocene or Vaqueros are well known and of widespread occurrence in the Coast Ranges of California; those of the Monterey, owing to the peculiar character of its sediments, are meager and little understood. A general survey of the fauna, however, indicates conditions approximate to those now existing in the coastal provinces, although certain forms of southern extraction, such as large cone shells, numerous arcas, and other types, indicate possible warmer environment. The evidence of the mollusks is supported by that of the plant remains, at least in so far as it relates to the region of Puget Sound, for there, according to Knowlton,[2] the presence of sumacs, chestnuts, birches, and sycamores in the upper Puget group [probable lower Miocene] would seem to indicate an approach from the subtropical conditions of the Eocene to the conditions prevailing at the present day.

PERIOD OF DIASTROPHISM IN THE MIDDLE MIOCENE

One of the most widespread and important periods of diastrophism in the Tertiary history of the Pacific Coast was that immediately following the deposition of the Monterey or lower middle Miocene. Its effects are visible from Puget Sound to southern California. It is marked as much by readjustment, by local faulting and folding as by general movements of elevation and subsidence. In some regions the

[1] *Bull. Dept. Geol. Univ. Cal.*, Vol. I, pp. 24 ff.

[2] *Tacoma Folio*, p. 3.

folding and faulting were intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. In other regions low broad folds were formed during the post-Monterey disturbance, and the strata were not upheaved to a great altitude. Faulting on a most magnificent scale took place along the earthquake rift and certain other fault-zones, especially that in the Salinas Valley, and along these lines of displacement, masses of granitic rocks, which during the preceding epoch had been subject to little or no erosion, were suddenly thrust upward and left exposed to the ravages of streams that assumed the proportions of torrents in certain regions, as for instance adjacent to the Carrizo Plain in south-central California. The post-Monterey disatrophic movements in the Puget Sound province also produced sharp relief as is evidenced by the coarse sediments deposited immediately following the disturbance. The localization of movement during the period is exemplified at numerous localities in the Coast Ranges.

Throughout much of the coastal belt, and probably likewise in the interior, great volcanic activity took place during the middle Miocene, this being the last epoch of volcanism in the Coast Ranges south of San Francisco. During this post-Monterey period of diastrophism general subsidence took place over most of the areas which were under water during the lower Miocene, and, in addition, extended northward from San Francisco Bay into the Sacramento Valley and along the coast to the California-Oregon line and southward down the Willamette Valley of Oregon. A new channel was apparently opened across the northwestern end of the Olympic Peninsula, and the Colorado Desert country of southern California and Arizona which for a very long time had presumably been free from marine conditions was occupied by an arm of the sea.

THE UPPER MIOCENE PERIOD

DISTRIBUTION AND CONDITIONS OF DEPOSITION

With the possible exception of that in the Eocene the subsidence immediately preceding and extending into the upper Miocene was the most important in the Tertiary history of the Pacific Coast. As a result, the formations of this epoch occupy a very considerable percentage of the surface of the present land-area. The sediments

in the southern Coast Ranges, especially, are largely derived from granitic rocks and are usually coarser at the base, becoming finer and finer toward the top, possibly indicating a subsidence greater than the concomitant sedimentation. Exceptions to the rule of coarse basal sediments are not uncommon, however, and in the Santa Cruz Mountains and also in eastern Monterey County, Cal., the unconformable deposition of fine shale directly upon older rocks is a well-marked phenomenon. This, of course, indicated a sudden and rather deep submergence of the areas in question at the initi ation of the upper Miocene. Conditions favoring the life of diatoms, so marked in the Monterey, continued over part of the Monterey diatomaceous shale territory during the upper Miocene (Santa Margarita and Fernando formations). The areas of maximum deposition during the period were apparently on the southwestern side of the San Joaquin Valley in western Fresno County and in central Ventura County, Cal., where thicknesses of over 8,000 feet of sediments, belonging largely to the upper Miocene, occur.

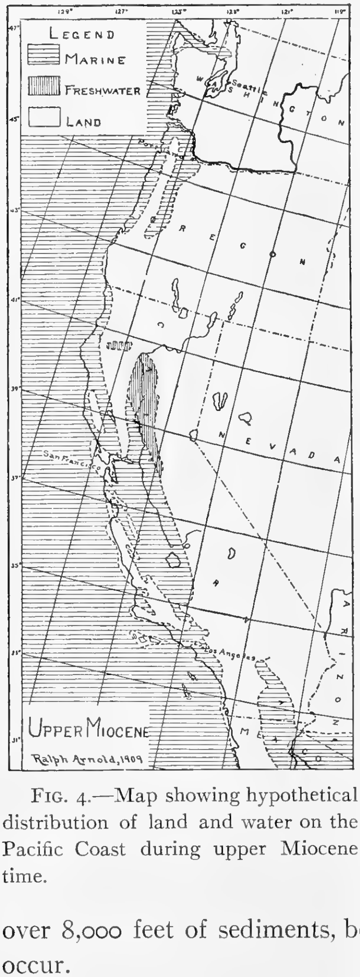

FIG. 4.—Map showing hypothetical distribution of land and water on the Pacific Coast during upper Miocene time.

EROSION AND VOLCANIC ACTIVITY

The peneplanation of the Klamath Mountains and the Sierra Nevada was probably completed during the upper Miocene, the detrital material from these land areas forming the great deposits in the San Joaquin and Sacramento valleys and the coastal belt of northern California. Erosion was practically continuous in these

first-mentioned areas from the beginning of the Eocene, but the final approach toward base level was probably not attained until the close of the upper Miocene. Volcanic activity had ceased on the Coast Ranges south of San Francisco during the inauguration of the upper Miocene, and had become subdued if not suppressed in the coastal belt to the north. In Oregon[1] and possibly also in the vicinity of Mount Diablo, east of San Francisco, in northeastern California, and in Washington volcanoes still persisted.

FAUNAS AND CLIMATE OF THE UPPER MIOCENE

The upper Miocene as here mapped and described embraces several formations, each carrying a more or less well-defined fauna. The most characteristic of these, in the order of age, are the Santa Margarita, typically developed in San Luis Obispo and Monterey counties, Cal., the Empire of Oregon, and the San Pablo of the San Joaquin Valley. All three of these indicate conditions approaching those of the present day, though leaning toward warmer climates. Toward the end of the Miocene and the beginning of the Pliocene, the forerunners of the upper Pliocene sub-boreal invasion which was to come, began to be felt. A cool-water fauna is found in the uppermost Etchegoin (upper Miocene) formation in the Coalinga district, this being followed by a freshwater fauna. In the lower Pliocene faunas of southern California are the last representatives of certain unique species of Pecten which were abundant in the upper Miocene of central California, but which migrated southward during the late Miocene, and became extinct before the Pliocene in the territory where they formerly had been so abundant. The abundance of huge oysters, pectens, and certain subtropical echinoid types in the Santa Margarita implies shallow, rather warm, water—these conditions being due in part, at least, to the local sheltered bodies of water which occupied the southern Coast Ranges during that period. The Empire fauna, best developed along the edge of the open upper Miocene ocean, extended from at least as far north as the Straits of Fuca to the region of the Santa Cruz Mountains and possibly farther south.

The strong resemblance between the Etchegoin fauna of the

[1] J. C. Merriam, *Bull. Dept. Geol. Univ. Cal.*, Vol. V, p. 173.

Kettleman Hills in southern Fresno County, Cal., and the Carrizo Creek beds of the Gulf province of southeastern California has led to the correlation of the latter with the former, although the writer's first examination of the Carrizo Creek fossils led to his placing them tentatively in the lower Miocene.[1] This correlation of the beds with the upper Miocene seems best to fit the conclusions based on other criteria such as faunal relations, character of sediments, sequence of geologic events in this province, etc.

THE PLIOCENE AND QUATERNARY PERIODS

CONDITIONS OF DEPOSITION AND CHARACTER OF SEDIMENTS

Sedimentation was continuous from the Miocene through the Pliocene and on into the Quaternary over large areas along the Pacific Coast, but there was a marked change in the conditions surrounding the deposition at various times within this long period. In a limited coastal belt, marine conditions marked the Pliocene and Quaternary as well as the upper Miocene, while farther inland freshwater, possibly alternating with short brackish-water or even marine, conditions prevailed during the Pliocene and Quarternary. This change from marine to lacustrine environment in the basin provinces of the Coast Ranges was probably brought about by two causes: first, a gradual elevation of the whole coast, and second, as suggested by Newsom,[2] movements along the earthquake rift and other faults in which certain of the blocks were elevated, forming barriers across pre-existing channels between the interior basins and the ocean. Faunal evidence indicates that those basins farthest inland, such as the San Joaquin Valley, became fresh possibly earlier in the Pliocene than those nearer the sea, such as the Santa Clara Valley basin.

The marine Pliocene deposits consist largely of fine sand and soft shale, and sometimes marl, while the freshwater sediments usually include considerable thicknesses of coarse, more or less incoherent gravels, hardened silt and sands. The maximum thickness of the marine Pliocene is attained in the Merced section immediately south of San Francisco, where approximately 4,000 feet of strata of Pliocene age are exposed. The greatest thickness of freshwater

[1] *Science*, N. S., Vol. XIX, 1904, p. 503.

[2] "Santa Cruz Folio," *Geologic Atlas U. S.*, 1909.

Pliocene occurs along the southwestern border of the San Joaquin Valley in western Fresno and Kings counties where the Tulare formation, largely of Pliocene age, attains a thickness of about 3,000 feet.

DIASTROPHISM AND VOLCANISM IN THE PLIOCENE

The most important movements inaugurating the Pliocene seem to have been an elevation of the Sacramento Valley and certain portions of the coastal belt of northern California and Oregon and the closing of the connection between the south end of the San Joaquin Valley and the southern California province. Although sedimentation was practically continuous from the Pliocene into the lowest part of the Pleistocene over much of the Pacific Coast, there is in parts of southern California a sharp line of unconformity between the Pliocene and Pleistocene. The extreme localization of the movements producing this unconformity is well exemplified at San Pedro, near Los Angeles, where the Pleistocene is separated from the Pliocene by an angular unconformity at Deadman Island, while half a mile distant on the mainland the same formations are perfectly conformable. Volcanic activities of a more or less complicated nature took place in certain portions of northern and central California during the Pliocene, while in the same period and probably up to a very recent date certain areas in the Sierra Nevada and Cascades have felt the effect of volcanism to a marked degree.

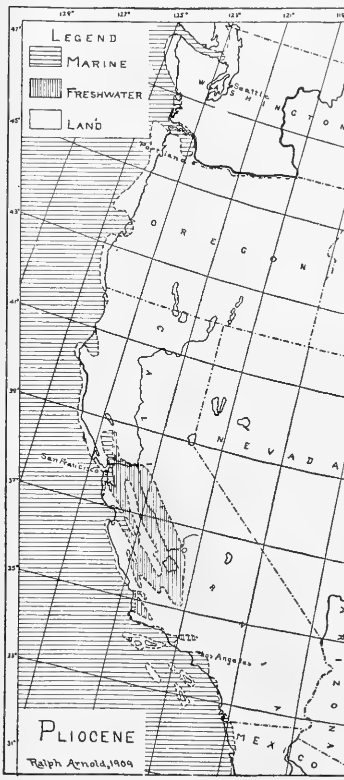

FIG. 5.—Map showing hypothetical distribution of land and water on the Pacific Coast during Pliocene time.

DIASTROPHISM IN THE QUATERNARY

Important and more or less widespread periods of diastrophism later than the one terminating the Monterey (middle Miocene) period of deposition occur in the Pleistocene. Up to the time of the discovery of certain indisputable evidence[1] regarding the Pleistocene age of beds affected by certain of these latest mountain-forming movements, the diastrophism had been considered as closing the Pliocene and initiating the Pleistocene. Minor movements producing local unconformities took place in central and southern California at various times during the Pleistocene in addition to the more far-reaching disturbances in the same epoch. The latest diastrophism, including the elevations and subsidences of the coast line, the recent movements along the earthquake rift, etc., are familiar to all. The localization of many of these movements is known already; the localization of many more of them will, it is believed, become clear when they are studied in detail.

FAUNAS AND CLIMATE OF THE PLIOCENE AND PLEISTOCENE

The faunas of the Pliocene and Pleistocene freshwater deposits are closely related and in some cases almost identical to the living faunas of the same province, while the marine faunas, on the other hand, indicate profound variation of environment, at least as regards temperature. Dr. Philip P. Carpenter[2] was the first to point out the cold-water faunas of the upper Pliocene and lower Pleistocene of the Pacific Coast. His conclusions have been strengthened by later workers, and in addition it has been shown that the latest Pleistocene faunas of the same region are of a type more tropical than those now inhabiting the shores of the Pacific Coast of the United States. It is thus evident that the warm temperature of the upper Miocene gave place to cooler conditions just before or at the beginning of the lower Pliocene, and to sub-boreal conditions in the upper Pliocene and lower Pleistocene. The later Pleistocene showed a very marked increase in oceanic temperature over the lower Pleistocene, even approaching subtropical warmth, and this, in turn, being followed by the conditions now prevailing. At some time during the upper

[1] *Mem. Cal. Acad. Sci.*, Vol. III, 1903, pp. 53–55.

[2] *Ann. and Mag. Nat. Hist.*, 3d Ser., Vol. XVII, 1866, p. 275.

Miocene and Pliocene, conditions prevailed favoring the migration of similar faunas into Japan and California or intermigration between the two. This is shown by the close similarity of certain pectens found in the upper Miocene in California, in still later beds in Alaska, and in the living fauna of Japan. The general resemblance of the late Tertiary faunas of California and Japan also favors this conclusion.

SUMMARY AND CONCLUSIONS

SUMMARY

Following the period of elevation and erosion at the close of the Cretaceous, the Eocene was inaugurated by a subsidence below sea-level of the greater part of western Washington and Oregon and the western part of central and southern California. Volcanic activity was pronounced in the early and middle Eocene. Later in the Eocene brackish- and freshwater conditions prevailed over the same area, and extended over much of Alaska. The fauna and flora of the Eocene were tropical to subtropical. The Oligocene was a period of elevation with marine conditions restricted to a much smaller area than in the Eocene. The fauna was transitional with stronger affinities toward the Miocene. The lower Miocene marked a widespread subsidence in the coastal belt which was followed by a period of mountain building and great local deformation, volcanism, etc. The Miocene faunas and floras indicate conditions comparable with those of the present day, or possibly a little warmer, except at the very close, when cool conditions began to prevail. The upper Miocene was a period of subsidence, with ideal conditions for maximum deposition of sediments in local basins. During Pliocene and early Pleistocene time there was a continuation of many of the upper Miocene conditions, except that marine environment gave place locally to freshwater. The marine fauna of the upper Pliocene and lower Pleistocene indicates sub-boreal conditions in southern California, followed by conditions in the middle or later Pleistocene more tropical than those of today. A period of elevation and considerable local deformation in the early Pleistocene inaugurated the present conditions on the Pacific Coast. Many of the movements occurring throughout the Tertiary were of local extent, and, for that reason,

correlation on a basis of diastrophism, unsupported by paleontologic evidence, is extremely hazardous.

CYCLES OF DIASTROPHISM

The period of the Tertiary uplift of the last worldwide cycle of diastrophism has been marked by two complete subcycles in the Pacific Coast of North America. The first was begun with gradual submergence in early Eocene, was continued by a gradual elevation in the later Eocene when marine conditions gave place to brackish- or freshwater conditions, and was completed by the epoch of uplift and erosion in the Oligocene. The second was initiated by submergence in the Miocene, was continued by the gradual elevation in the Pliocene, when, as in the later Eocene, freshwater conditions supplanted marine, and has been practically completed by the Quaternary uplift which marks the present position of the continent.

PERIODS OF MAXIMUM ELEVATION AND SUBSIDENCE

The periods of marked elevation were the Oligocene, late Pliocene, and Quaternary; the periods of maximum subsidence were the middle Eocene and upper Miocene; the periods of greatest volcanic activity were the middle Eocene and the middle Miocene. It is noteworthy that the periods of maximum volcanic activity were practically coincident with the periods of maximum subsidence in adjacent areas.

CHANGES IN CLIMATE

The climate was tropical to subtropical in the Eocene, transitional from this to warm temperate in the Oligocene, warm temperate in the Miocene, transitional from this to sub-boreal in the lower Pliocene, sub-boreal in the upper Pliocene and lower Pleistocene, and warm temperate in the later Pleistocene.

DIASTROPHIC PROVINCES

The study of the Tertiary history of the Pacific Coast shows the following positive elements or areas of persistent uplift in the coastal belt: The Olympic Mountains; a more or less uncertain, probably disconnected, belt along the western part of Washington and Oregon; the region of the California-Oregon line and thence eastward toward the Blue Mountains of southeastern Washington; the Santa Lucia Range, south of Monterey Bay; the region north and northeast of

	Coalinga District	Ventura County	Los Angeles County	San Diego Region
	Alluvium	Alluvium	Alluvium	Alluvium
	Stream Deposits	—Unconformity—	San Pedro	San Pedro
				—Unconformity—
			—Unconformity—	
			Beds at Deadman Is.	
	Tulare			
			Beds at Third St. Tunnel and Temescal Canyon	San Diego
		Fernando	Fernando	
	—Unconformity—			
				Beds at Carrizo Creek
	Etchegoin			
	—Unconformity—			
	Jacolitos			
	Santa Margarita			
		—Unconformity—	—Unconformity—	
Cenozoic		Modelo		
	—Unconformity—			
	Vaqueros	Vaqueros		
			Puente	
	—Unconformity—			
		Sespe (Oligocene ?)	Sespe (Oligocene ?)	
				—Unconformity—
	Tejon			
		Topatopa		Martinez or Tejon
Mesozoic	Chico		Chico	

Table of Tentative Correlations of the Tertiary Formations of California, Oregon, and Washington

Ralph Arnold—January, 1909

Age	Standard California Section	Central Washington	Western Washington	Eastern Oregon	Western Oregon	Mount Diablo Region	Santa Cruz Mountains	San Luis Folio	Santa Maria District	Coalinga District	Ventura County	Los Angeles County	San Diego Region
Quaternary: Recent	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
Quaternary: Pleistocene	San Pedro		Vashon		Marine Sands	Marine Sands —Unconformity—	Marine Sand —Unconformity—	Marine Sands -Unconformity—	Marine Sands —Unconformity -	Stream Deposits	—Unconformity -	San Pedro	San Pedro —Unconformity—
	Unconf.— Unconf.		Admiralty									—Unconformity —	
Tertiary: Pliocene												Beds at Deadman Is.	
	Merced			Rattlesnake		"Siestan"	Merced / Santa Clara	Paso Robles		Tulare			
						—Unconformity—							
	San Diego					"Orindan"	Purisima		Fernando		Fernando	Beds at Third St. Tunnel and Temescal Canyon; Fernando	San Diego
			—Unconformity—	—Unconformity—						—Unconformity—			
Tertiary: Miocene					Empire					Etchegoin —Unconformity—			Beds at Carrizo Creek
	San Pablo		Beds at Clallam Bay, Quillayute River, Sooke beds			San Pablo (Ione?)		—Unconformity—		Jacolitos			
	—Unconformity—	Ellensburg				Beds in Contra Costa County	Santa Margarita	Pismo / Santa Margarita		Santa Margarita			
	Santa Margarita					—Unconformity—	—Unconformity—	—Unconformity—	—Unconformity —		—Unconformity—	—Unconformity -	
	—Unconformity -	Yakima Basalt	—Unconformity—	Columbia River Basalt		Monterey	Monterey	Monterey	Monterey		Modelo		
	Monterey		Beds at Port Blakeley, Fuca Strait		Astoria Group: "Astoria" sandstone		—Unconformity -			—Unconformity—			
	-Unconformity -												
	Vaqueros					Vaqueros	Vaqueros —Unconformity—	Vaqueros	Vaqueros	Vaqueros Unconformity -	Vaqueros	Puente	
Tertiary: Oligocene	Unconformity—			—Unconformity—									
	San Lorenzo		Puget Group: Beds at Porter, Bean Point, Fuca Strait, etc.	John Day	Astoria Group: "Astoria" shale / Oakland (?)		San Lorenzo		Sespe (Oligocene?)		Sespe (Oligocene?)	Sespe (Oligocene?)	—Unconformity —
	—Unconformity(?)—	—Unconformity—		—Unconformity—	Tyee								
Tertiary: Eocene									Tejon	Tejon			
	Tejon	Manastash	Puget Group: Beds at Little Falls (freshwater)	Clarno	Arago: Coaledo	Tejon					Topatopa		Martinez or Tejon
		—Unconformity—											
		Roslyn	Puget Group: Beds at Little Falls (marine)		Arago: "Pulaski" Umpqua		Limestone inclusions in diabase						
	Martinez	—Unconformity—				Martinez							
		Swauk	Beds at Port Crescent					—Unconformity—					
	—Unconformity—	—Unconformity—		—Unconformity—	—Unconformity—								
Mesozoic: Cretaceous: Upper Cret.	Chico			Chico	Chico	Chico	Chico	Chico		Chico		Chico	
Mesozoic: Cretaceous: Lower Cret.					Shasta ("Myrtle")				Knoxville				

San Diego; and the Peninsula of Lower California. The Sierra Nevada and Sierra Madre and San Bernardino and San Jacinto mountains may also be considered in the same class. The region of Santa Catalina and San Clemente islands off southern California belong to an area about which little is known previous to the Miocene, although it is the belief of the writer that they are in a belt of more or less persistent uplift.

The negative elements or areas of persistent subsidence are: Puget Sound; the Willamette Valley; the San Joaquin Valley, and the Sacramento Valley to a less degree; central Ventura County; and, since the Eocene, the Salinas Valley, and the vicinity of Los Angeles.

THE GASES IN ROCKS[1]

R. T. CHAMBERLIN
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It has been known for a long time from microscopic studies that some minerals inclose minute cavities which contain both liquid and gaseous matter. For a much shorter period it has been known that various igneous rocks, when exposed to red heat in a vacuum, evolve several times their volume of gas, and that this gas is of quite variable composition. Since these gases occur in proportions entirely different from those of the constituents of the air, it has not seemed probable that they were derived directly from our present atmosphere, unless the rocks manifest some power of selective absorption not now understood. The apparent difficulties involved in this conception have suggested that some earlier atmosphere was rich in those gases. This involves a hypothesis relative to the changes through which the atmosphere has passed, and leads on to a theory of its origin and that of the earth itself. An alternative hypothesis regards these gases, not as the products absorbed by a molten earth from its surrounding gaseous envelope, but as entrapped in the body of the earth during its supposed accretion, and hence as a source from which accessions to our present atmosphere might be derived. A study of the gases in the rocks has seemed, therefore, to give promise of results of some value to atmospheric problems and, perhaps, to those of cosmogony. Because of this, it has appeared advisable to determine more widely the range and the distribution of these gases, their relations to other geologic phenomena, and the states in which the gases, or gas-producing substances, exist in the rocks.

THE ANALYSES CLASSIFIED

In these studies the gases were extracted for analysis by heating the powdered rock material to redness in a vacuum and pumping off

[1] This paper presents in a brief form some of the results discussed at greater length in "The Gases in Rocks," *Publication No. 106* of the Carnegie Institution of Washington. For a detailed description of the analyses, a discussion of the chemical aspects of the problem, and an outline of the work previously done in this field, recourse must be had to the original paper.

the evolved gas. In all, 112 complete analyses were made besides numerous special or partial analyses connected with various experiments. These may perhaps be most advantageously and briefly shown when collected into groups. To make these tables as complete as possible, not only the results of the author's studies, but all the available analyses of other investigators, have been included in the lists. Except in the case of four of the five analyses by Tilden, relative to which sufficient data are not given, all of the figures in these tables refer to volumes of gas per volume of rock. Previous investigators have usually given the total volume of gas and the percentages of each constituent. From these I have calculated the volumes for each individual gas. The numbers in the first column are the analysis numbers used in Table 8 of the original paper.[1]

In making the averages of the analyses, it should, perhaps, be stated that in those cases where, on account of excessive carbonation of the rocks, no figures are given for carbon dioxide, the average amount of this gas calculated from the other analyses is assumed to be present. This addition is made to the average total and makes this figure slightly greater than the average of the column which it foots. The same method has been used for carbon monoxide in the three of Travers' analyses where carbon monoxide and hydrogen are put together.

The figures for the Orgueil meteorite which yielded such a remarkable amount of sulphur dioxide make the average for the sulphur gases an abnormal one. The presence of this gas in quantity must mean that the meteorite has suffered much from weathering and oxidation subsequent to its fall. Considerable troilite has passed into iron sulphate which has been decomposed by the heat of the combustion-furnace.

Omitting the sulphur dioxide of this specimen, the average total volume of gas from stony meteorites is reduced to 4.80 times the volume of the meteoritic material.

Methane was determined in only two of these analyses. In these two it averaged 0.10 volume; but in order to make the figures consistent in the table, it was necessary to average these as if the eight other meteorites yielded no marsh-gas, though it is highly probable

[1] *Carnegie Publication No. 106*, pp. 14–22.

TABLE I

ANALYSES CLASSIFIED BY GROUPS OF ROCKS

No.	Rock and Locality	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	Granites and gneisses of igneous origin								
	Granite, Skye (per cent.)	.....	28.60	6.45	3.02	61.68	5.13	99.88	Tilden
	Granite, Vire (average)	0.05	.86	.35	.12	5.29	.04	6.71	Gautier
	Granitoid porphyry, L'Esterel	.....	4.50	.32	.19	2.36	.16	7.53	Do
1	Medium-grained, white granite	.....	.28	.07	.07	.92	.10	1.44	Chamberlin
2	Coarse-grained, reddish granite	.....	.42	.09	.10	2.94	.11	3.66	Do
4	Laurentian gneiss, Ontario	.....	.31	.08	.06	1.50	.13	2.08	Do
9	Pike's Peak granite	.....	.37	.05	.02	.04	.12	.60	Do
19	Granite porphyry, Menominee	.....	3.51	.72	.06	2.34	.22	6.85	Do
20	Fine-grained gneiss, Menominee	tr.	1.89	.23	.02	.43	.23	2.80	Do
21	Fine-grained banded gneiss, Menominee	.....	6.63	1.13	.06	1.37	.08	9.27	Do
22	Laurentian granite, Marquette	.....	1.89	.13	.03	.74	.15	2.94	Do
24	Pink granite, North Carolina	tr.	.16	.05	.02	.38	.04	.65	Do
25	Gray granite, Quincy, Mass.	tr.	.39	.09	.06	1.04	.02	1.60	Do
26	Gray granite, Russia	tr.	1.79	.18	.....	.99	.....	2.96	Do
33	Laurentian gneiss, Marquette	tr.	.85	.15	.07	1.79	.12	2.98	Do
37	Oglesby blue granite, Georgia	tr.	1.13	.11	.03	1.06	.05	2.38	Do
38	Stone Mountain granite, Georgia	tr.	.08	.03	.01	.60	.04	.76	Do
39	Ortonville granite, Minn.	tr.	1.20	.05	.01	.05	.05	1.36	Do
57	Granite porphyry bowlder, New York	.04	carb.	.27	.02	.85	.04	1.22	Do
66	Gneiss of igneous origin, Ontario	tr.	.28	.13	.03	.95	.08	1.47	Do
	Average of 19 analyses	tr.	1.47	.22	.05	1.36	.09	3.19	
	The syenite group								
44	Nephelite syenite, Ontario	.....	0.29	0.05	0.04	0.25	0.05	0.68	Chamberlin
51	Shonkinite, Highwood Mountains, Mont.	tr.	.11	.06	.05	.95	.05	1.22	Do
53	Quartz syenite porphyry, Colorado	.....	carb.	.11	.08	.22	.03	.44	Do
56	Hornblende syenite, Maine	tr.	.15	.07	.03	2.22	.03	2.50	Do
	Average of 4 analyses	tr.	.18	.07	.05	.91	.04	1.25	

TABLE I—*Continued*

No.	Rock and Locality	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	The gabbro-diorite group								
	Gabbro, Lizard, England (per cent.)	.....	5.50	2.16	2.03	88.42	1.90	100.01	Tilden
	Gabbro, Isle of Skye	.....	.00	.00	.....	1.40	.....	1.40	Travers
15	Gabbro diorite, Mt. Sneffels, Colo	.....	.40	.10	.04	1.13	.14	1.81	Chamberlin
16	Gabbro, summit of Mt. Sneffels	.....	carb.	.12	.02	.97	.12	1.23	Do
17	Orthoclase gabbro, Duluth	.....	.44	.12	.07	2.68	.33	3.64	Do
32	Schistose gabbro, Menominee	0.02	20.07	.58	.20	8.54	.32	29.73	Do
36	Olivine gabbro, Duluth	tr.	.16	.07	.04	.52	.05	.84	Do
52	Theralite, Crazy Mountains, Mont	tr.	1.08	.17	.04	.93	.03	2.25	Do
58	Intrusive, Highwood Mountains, Mont	.....	.28	.07	.04	.45	.03	.87	Do
60	Diorite plug in shales, Colorado	.03	.22	.06	.05	1.10	.06	1.52	Do
73	Coarse diorite bowlder, Maine	.06	.27	.07	.04	1.29	.05	1.78	Do
74	Diorite, Penobscot Bay, Me	.07	.21	.04	.20	3.95	.14	4.61	Do
	Average of 11 analyses	.02	2.31	.13	.07	2.09	.11	4.73	
	Diabases and basalts								
	Basalt, Antrim	.....	2.57	1.61	0.80	2.89	0.13	8.00	Tilden
	Ophite, Villefranque (average)	.24	2.39	.33	.08	4.52	.02	7.58	Gautier
	Lherzolite, Lherz	1.86	12.29	.31	tr.	1.15	tr.	15.61	Do
11	Keweenawan diabase, Wisconsin	.....	.59	.05	.19	3.83	.25	4.91	Chamberlin
34	Keewatin greenstone, Mesabi	.19	20.08	1.16	.09	10.10	.57	32.19	Do
35	Keweenawan diabase, Minnesota	.01	.25	.06	.06	3.15	.06	3.59	Do
45	Iron basalt, Greenland	tr.	3.74	1.74	.17	2.24	.16	8.05	Do
50	Nephelite melilite basalt, Texas	.05	1.07	.20	.06	1.16	.10	2.64	Do
61	Diabase, Nahant, Mass	.19	4.91	.21	.12	3.13	.15	8.71	Do
84	Vogesite, La Plata, Colo	.....	carb.	.14	.03	1.08	.05	1.30	Do
85	Keweenawan diabase, Michigan	tr.	1.31	.09	.09	2.34	.05	3.88	Do
110	Basalt of 1868, Kilauea, Hawaii	.01	.60	.18	.02	.02	.02	.85	Do
111	Lava of 1906, Vesuvius	.03	.31	.05	.01	.01	.01	.42	Do
112	Lava of 1906, Vesuvius	.14	.39	.05	.02	.01	.01	.62	Do
	Average of 14 analyses	.19	3.96	.44	.12	2.54	.11	7.36	

TABLE I—*Continued*

No.	Rock and Locality	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	Andesites								
13	Andesite, Ouray Co., Colo.	.....	carb.	0.09	0.02	0.08	0.08	0.27	Chamberlin
47	Andesite, Red Mountain, Ariz.	tr.	5.12	.57	.30	.12	.26	6.37	Do
62	Andesite, Rosita Hills, Colo.	tr.	carb.	.27	.05	.30	.13	.75	Do
64	Andesite, Lipari Islands	tr.	.56	.04	.01	.17	.02	.80	Do
70	Andesite, Granite Mountain, Utah	tr.	2.66	.16	.03	.53	.05	3.43	Do
72	Phonolite trachyte, Pike's Peak	tr.	.76	.05	.03	.19	.06	1.08	Do
91	Andesite, summit of Orizaba	.....	.22	.05	.00	.01	.03	.31	Do
	Average of 7 analyses	.....	1.86	.18	.06	.20	.09	2.39	
	Rhyolites								
10	Rhyolite, Marble Mountain, Arizona	.....	0.22	0.08	0.04	0.03	0.13	0.50	Chamberlin
49	Rhyolite vitrophyre, Telluride	.....	2.33	.05	.03	.07	.03	2.51	Do
	Pitchstone rhyolite, Rosita Hills	.....	.07	.....	.13		.....	.20	Do
59	Nevadite, Chalk Mountain, Colo.	.....	.15	.06	.01	.02	.03	.27	Do
	Average of 4 analyses	.....	.69	.05	.02	.06	.05	.87	
	Schists								
3	Keewatin schist, Mesabi	.....	7.67	0.28	0.05	3.81	0.22	12.03	Chamberlin
23	Schist with chloritoid, Black Hills	.....	.46	.10	.04	3.07	.05	3.72	Do
	Average	.....	4.06	.19	.05	3.44	.13	7.87	
	Miscellaneous porphyries								
14	Coarse porphyry, Ouray Co., Colo.	.....	carb.	0.05	0.02	0.22	0.01	0.30	Chamberlin
78	Topaz quartz-porphyry, Saxony	.....	.32	.08	.05	.44	.08	.97	Do
	Average	.....	.32	.06	.04	.33	.04	.79	

TABLE I—*Continued*

No.	Rock and Locality	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	Quartz								
	Smoky quartz, Branchville, Conn.	tr.	0.07	0.00	0.00	0.00	tr.	0.07	Wright
71	Vein quartz, Iron Co., Utah	.....	.11	.09	.03	.53	.05	.81	Chamberlin
83	Crystals (aqueous origin), North Carolina	tr.	.03	tr.	tr.	.01	.03	.08	Do
100	Auriferous quartz, New South Wales	0.01	.66	.03	.04	.12	.02	.88	Do
103	Quartz from pegmatite, Baltimore	.....	.09	.02	tr.	.01	.01	.13	Do
105	Quartz from lava, Utah	tr.	.12	.05	.00	tr.	.03	.20	Do
	Average of 6 analyses	.....	.18	.03	.01	.11	.02	.35	
	Metamorphosed sedimentaries								
	Pyroxene gneiss, Ceylon (per cent.)	.....	77.72	8.06	0.56	12.49	1.16	99.99	Tilden
	Gneiss, Seringapatam (per cent.)	.....	31.62	5.36	.51	61.93	.56	99.98	Do
27	Baltimore gneiss, Bryn Mawr, Pa.	tr.	.13	.10	.14	4.32	.04	4.73	Chamberlin
28	Baltimore gneiss, Schuylkill River	.30	1.35	.22	.11	4.02	.10	6.10	Do
29	Wissahickon mica gneiss, Pennsylvania	tr.	.19	.07	.02	.65	.04	.97	Do
30	Wissahickon gneiss, Schuylkill River	tr.	.19	.08	.08	1.90	.08	2.33	Do
31	Cambrian gneiss, Coatesville, Pa.	.....	.26	.09	.01	.37	.03	.76	Do
43	Sillimanite gneiss, Quebec	SO_2 2.76	2.05	.09	.03	.05	.07	5.05	Do
54	Altered Jurassic shale, Colorado	tr.	carb.	.15	.04	.45	.04	.68	Do
55	Garnetiferous gneiss, Quebec	.11	.16	.07	.02	.41	.02	.79	Do
65	Fine-grained gneiss, Ontario	SO_2 4.15	.68	.....	.05		....	4.88	Do
67	Feather amphibolite, Ontario	tr.	carb.	.48	.03	.32	.06	.90	Do
68	Amphibolite, Ontario	tr.	carb.	.26	.05	2.01	.06	2.31	Do
69	Rice Rock, Sudbury, Ont.	.16	.47	.16	.05	2.32	.06	3.22	Do
92	Amphibolite, Chester, Mass.	.....	2.23	1.10	.10	2.84	.13	6.40	Do
	Average of 13 analyses	.57	.77	.22	.05	1.52	.05	3.18	

TABLE I—*Continued*

No.	Rock and Locality	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	*Shales**								
5	Kinderhook shale, Burlington, Ia	.....	9.28	0.35	0.12	0.22	0.15	10.12	Chamberlin
6	Portage shale, Ithaca, N. Y.	.....	1.47	.83	.16	1.23	leak	3.69	Do
18	Hamilton shale, Marysville, Pa.	tr.	.41	.17	.07	1.45	.40	2.50	Do
41	Hamilton shale, Nashville, Tenn.	29.38	20.10	4.38	.....	37.03	.....	90.89	Do
42	Oil shale, Platteville, Wis.	3.90	10.43	4.82	20.67	7.57	1.26	48.65	Do
	Average of first 3 analyses	.....	3.75	.45	.11	.97	.18	5.43	
	Sandstones and quartzites								
8	Potsdam sandstone, Baraboo, Wis.	.....	0.47	0.18	.....	0.01	0.38	1.04	Chamberlin
12	Quartzite schist, Baraboo, Wis.	.....	.16	.07	.03	.03	.06	.35	Do
75	Potsdam sandstone, Ablemans, Wis.	tr.	.09	.05	.02	.13	.05	.34	Do
76	Same as last, powdered and reheated	tr.	.05	.07	.02	.23	.08	.45	Do
77	Huronian quartzite, Baraboo, Wis.	tr.	.11	.04	.01	.24	.03	.43	Do
78	Red Beds, Colorado City	tr.	carb.	.71	.07	.32	.06	1.16	Do
80	St. Peter sandstone, Minnehaha Falls	tr.	.02	tr.	.01	tr.	.01	.04	Do
81	Same as last, powdered and reheated	.....	.03	.07	.01	.17	.21	.49	Do
82	Quartzite, Grenville series, Quebec	.23	.21	.04	.01	.09	.01	.59	Do
97	Micaceous quartzite, Uinta Mountains	.01	.57	.12	.03	.63	.06	1.42	Do
98	Quartzite, Rib Hill, Wis.	.01	.62	.06	.02	.17	.02	.90	Do
99	Same as last, granules used	tr.	.86	.01	tr.	.02	tr.	.89	Do
	Average of 12 analyses	.02	.29	.11	.02	.17	.08	.69	

* The two bituminous shales which derived the bulk of their gas from the distillation and decomposition of organic matter are necessarily omitted from the average.

TABLE II

VARIOUS MINERALS

No.	Mineral and Locality	H_2S	CO_2	CO	H_2	CH_4	N_2	A+ He	Total	Analyst
	Feldspar	.....	1.20	0.01	0.03	0.01	0.02	.....	1.27	Dewar
	Celestial graphite	.....	6.66	.....	.18	.39	tr.	.....	7.25	Do
	Graphite, Borrodale	.....	.95	.20	.58	.68	.17	.....	2.60	Do
	Chlorite, Zoptan, Moravia	.....	.33	1.33	5.84	.....	.....	.....	7.50	Travers
	Serpentine, Zermatt	.....	.....	.....	2.08	.....	.....	.....	2.08	Do
	Mica, Westchester, Pa.	.....	.42	.22		.....	.....	.....	.64	Do
	Talc, Greiner, Tyrol	.....	.19	.11		.....	.....	.....	.30	Do
	Feldspar, Peterhead granite	.....	3.08	.55		.....	.....	.....	3.63	Do
	Malacone	.....	1.55	.....	.03	.....	.02	.17	1.77	Kitchin and Winterson
7	Muscovite, Canada	.....	1.26	.12	.10	.04	.27	.....	1.79	Chamberlin
40	Biotite, Ortonville granite	0.22	12.45	.23	.30	.06	.21	.....	13.47	Do
48	Pyroxene crystals, Red Mountain	.10	.69	.16	.08	.01	.06	.....	1.10	Do
63	Anorthosite, Quebec	tr.	2.36	.27	.56	.02	.06	.....	3.27	Do
90	Wollastonite, Lewis Co., N. Y.	.....	2.37	.18	.06	.02	.08	.....	2.71	Do
93	Pitchblende, Beaver Co., Colo.	sul.	carb.	.24	.07	.03	.27	.37	.98	Do
94	Carnotite	tr.	2.46	.23	.05	.02	.22	.04	3.02	Do
95	Greenalite rock, Mesabi	tr.	.42	.24	5.18	tr.	.15	.....	5.99	Do
96	Grünerite rock, Mesabi	.02	1.14	.26	1.39	.02	.19	.....	3.02	Do
101	Beryl, pegmatite, New England	tr.	.16	.01	.31	.01	.02	.....	.50	Do
102	Pegmatite with tourmaline	tr.	.06	.06	1.45	.05	.04	.....	1.66	Do
104	Albite, Yancey Co., N. C.	.....	tr.	.01	.04	.02	.....	.....	.07	Do
	Average of 21 analyses	.02	1.88	.19	.92	.06	.08	.03	3.18	

that this gas was present and has been included in the figures given for hydrogen.

The unusual amount of gas from the Arva specimen recalls the behavior of the Toluca meteorite,[1] which, at the first attempt, produced 24.42 volumes of gas, owing to the presence of a small quantity of iron rust, but whose pure metal evolved only 1.85 volumes. An average, omitting the Arva, is therefore made.

TABLE III

STONY METEORITES

No.	Meteorite	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	Guernsey, Ohio....	.....	1.80	0.13	0.06	0.95	0.05	2.99	Wright
	Pultusk, Poland....	.....	1.06	.06	.06	.52	.04	1.75	Do
	Parnallee, India ...	...	2.13	.04	.05	.36	.04	2.63	Do
	Weston, Conn......	.....	2.83	.08	.04	.46	.08	3.49	Do
	Iowa County, Iowa	.....	.88	.05	...	1.45	.12	2.50	Do
	Kold Bokkeveld ...	.....	23.49	.61	.82	.10	.21	25.23	Do
	Dhurmsala, India..	.....	1.59	.03	.10	.72	.03	2.51	Dewar
	Pultusk, Poland ...	.....	2.34	.19	.27	.64	.09	3.54	Do
	Mocs...........	.....	1.25	.07	.09	.45	.07	1.94	Do
	Orgueil..........	SO_2 48.03	7.40	1.14	.87	....	.33	57.87	Do
106	Allegan, Mich......	tr.	.21	.19	.01	.08	tr.	.49	Chamberlin
107	Estacado, Texas...	tr.	.24	.25	.03	.31	.01	.84	Do
	Average of 12 analyses.......	4.00	3.77	.24	.20	.50	.09	8.80	

TABLE IV

IRON METEORITES

No.	Meteorite	H_2S	CO_2	CO	CH_4	H_2	N_2	Total	Analyst
	Lenarto............	.....	0.13	0.00	.....	2.44	0.28	2.85	Graham
	Augusta Co., Va....	.....	.31	1.21	....	1.14	.51	3.17	Mallet
	Tazewell Co., Tenn.	.....	.46	1.31	....	1.35	.05	3.17	Wright
	Shingle Springs, Cal.	.....	.13	.12	.....	.67	.05	.97	Do
	Cross Timbers, Tex.	.....	.11	.19	.....	.99	.....	1.29	Do
	Dickson County, Tex	.....	.29	.34	.....	1.57	.....	2.20	Do
	Arva, Hungary......	.....	5.92	31.91	...	8.57	.73	47.13	Do
	Cranbourne, Australia...........	...	.04	1.13	0.16	1.63	.63	3.59	Flight
	Rowton, Shropshire	.....	.33	.47	...	4.96	.62	6.38	Do
108	Toluca, Mexico.....	tr.	.12	1.32	.04	.27	.10	1.85	Chamberlin
	Average..........	.....	.78	3.80	.02	2.36	.30	7.26	
	Average omitting Arva meteorite.	.....	.21	.67	.02	1.67	.24	2.83	

[1] *Carnegie Publication No. 106*, p. 22.

AVERAGES OF THE GROUPS

TABLE V

IGNEOUS ROCKS

No.	Type of Rock	No. of Analyses	H_2S	CO_2	CO	CH_4	H_2	N_2	Total
1	Basic schists	2	0.00	4.06	0.19	0.05	3.44	0.13	7.87
2	Diabases and basalts	14	.19	3.96	.44	.12	2.54	.11	7.36
3	Gabbros and diorites	11	.02	2.31	.13	.07	2.09	.11	4.73
4	Granites and gneisses	19	.00	1.47	.22	.05	1.36	.09	3.19
5	Andesites	7	.00	1.86	.18	.06	.20	.09	2.39
6	Syenites	4	.00	.18	.07	.05	.91	.04	1.25
7	Rhyolites	4	.00	.69	.05	.02	.06	.05	.87
8	Miscellaneous porphyries	2	.00	.32	.06	.04	.33	.04	.79

The general averages bring out the fact that, while rocks of each group may vary considerably among themselves, each group as a whole fits into a logical place in relation to the other groups. The established order appears to be, most gas from those rocks which contain the greatest proportion of ferromagnesian minerals. Though much influenced by other conditions, such as relative age and nature of the igneous mass, the general deduction may be made that the volume of gas obtained from rocks varies, in a rough way, in proportion to the percentage of ferromagnesian minerals present. Diabases, basalts, and basic schists take first rank in the quantity of gas evolved. Next to them appear diorites and gabbros which are also near the basic end, but formed under different conditions. Andesites are out of their place in this list, as they take precedence over granites in the proportion of ferromagnesian minerals, but these andesites were all either of Tertiary or Recent age, whereas most of the granites came from pre-Cambrian formations, and, as the next table will show, ancient igneous rocks yield more gas than modern ones. The rhyolites, which combine a scarcity of basic minerals with Tertiary age, foot the list.

It is to be noted that the rank of a type of rock on the basis of an individual gas does not in all cases correspond to its rank for some other gas, or in respect to total volumes. The andesites tested gave more carbon dioxide than either the granites or the syenites, though both of these types greatly surpassed the andesites in the matter of hydrogen. But this involves another factor: in deep-seated rocks,

hydrogen and carbon dioxide are of about equal importance; in surface flows, carbon dioxide predominates. Though carbon monoxide and methane are somewhat variable, the minor gases generally increase or decrease with the total volumes.

TABLE VI

ROCKS OF SEDIMENTARY ORIGIN

Order	Type of Rock	No. of Analyses	Sulphur gases	CO_2	CO	CH_4	H_2	N_2	Total
1	Shales (non-bituminous) .	3	0.00	3.72	0.45	0.11	0.97	0.18	5.43
2	Metamorphosed sediments	13	.57	.77	.22	.05	1.52	.05	3.18
3	Sandstones and quartzites	12	.02	.29	.11	.02	.17	.08	.69

Among sedimentary rocks, sandstones and quartzites yield less gas than shales, while the metamorphic group, comprising both altered shales and sandstones, together with modified limestones, take an intermediate position, though they surpass shales in hydrogen and the sulphur gases.

TABLE VII

METEORITES

Order	Type of Meteorite	No. of Analyses	Sulphur gases	CO_2	CO	CH_4	H_2	N_2	Total
1	Stony	12	4.00	3.77	0.24	0.20	0.50	0.09	8.80
	Without SO_2 of Orgueil	12	.00	3.77	.24	.20	.50	.09	4.80
2	Iron	10	.00	.78	3.80	.02	2.36	.30	7.26
	Neglecting Arva	9	.00	.21	.67	.02	1.67	.24	2.83

A comparison of the two types of meteorites indicates that carbon dioxide is much more important in the gas from stony specimens than in that from the metallic bodies, but that iron meteorites yield several times as much carbon monoxide and hydrogen as do the stones. Sufficient data are not at hand to permit a comparison of the amount of marsh-gas from these two types; nitrogen, however, appears to come in greater volume from the iron meteorites.

ANALYSES CLASSIFIED BY THE AGE OF THE ROCKS[1]

In addition to those rocks which could be classed either as Archean or Proterozoic, there were others which could only be called pre-

[1] In this classification of analyses by the age of the rocks, and in the following one based on granularity, only my own analyses have been used.

Cambrian; they are included under the head of Total pre-Cambrian.

TABLE VIII

IGNEOUS ROCKS

Order	Age of Rocks	No. of Analyses	H_2S	CO_2	CO	CH_4	H_2	N_2	Total
1	Archean	7	0.03	7.44	0.35	0.07	3.79	0.21	11.89
2	Proterozoic	8	.00	1.85	.31	.07	2.08	.16	4.47
3	Tertiary	18	.00	1.20	.13	.05	.53	.07	1.98
4	Recent lavas	5	.03	.41	.07	.01	.06	.02	.60
	Total pre-Cambrian	28	.02	2.76	.23	.06	2.12	.12	5.31
	Grand total	51	.01	2.16	.18	.05	1.36	.09	3.85

The rapid and steady decline in the quantity of every gas, in passing down the columns from the Archean through the Proterozoic and Tertiary to Recent lavas, is very striking. These differences may be due to a combination of causes. The older rocks may yield more gas than the recent, owing to metasomatic changes which have been slowly taking place within the rocks. If this be so, the analyses indicate that this process is progressing at an exceedingly slow rate. Or the early magmas may have been more highly charged with gas, some of which has escaped as they were worked over and over and brought to the surface in later times. Both of these processes have probably been operative.

TABLE IX

SEDIMENTARY AND META-SEDIMENTARY ROCKS

Order	Age of Rocks	No. of Analyses	H_2S SO_2	CO_2	CO	CH_4	H_2	N_2	Total
1	Proterozoic	17	0.45	0.68	0.17	0.04	1.32	0.05	2.71
2	Paleozoic	10	.00	1.34	.25	.05	.41	.13	2.28
3	Mesozoic	1	.00	carb.	.15	.04	.45	.04	.68
	Total	28	.27	.93	.20	.04	.96	.08	2.48

Age appears to make less difference in the gas evolved from sedimentary or meta-sedimentary rocks than it does in the case of igneous rocks. All of the Proterozoic specimens were of metamorphic types while only one of the Paleozoic sediments had been metamorphosed. The Mesozoic representative was a Jurassic shale altered by an intru-

sive. The unusual amount of sulphur gas in the Proterozoic list is due to two weathered rocks which contained iron sulphate. However, even with these omitted, the hydrogen sulphide is abnormally high in the rocks of this age. One of the Paleozoic shales was so calcareous as to yield 9.28 volumes of carbon dioxide, which accounts for the large quantity of this gas. The two bituminous shales (analyses 41 and 42) are not included in these averages, since their excessive volume of gas from organic sources would so influence the figures as to disguise some of the characteristics of the other rocks.

ANALYSES CLASSIFIED BY THE GRANULARITY OF THE ROCKS

TABLE X

IGNEOUS ROCKS

Order	Granularity	No. of Analyses	H_2S	CO_2	CO	CH_4	H_2	N_2	Total
1	Fine-grained............	22	0.02	2.75	0.31	0.06	1.68	0.12	4.94
2	Medium-grained...... ..	18	.01	2.37	.17	.05	1.41	.10	4.11
3	Coarse-grained..........	11	.01	.40	.10	.04	1.20	.08	1.83
4	Various porphyries (mostly Tertiary).........	5	.00	.41	.07	.04	.22	.05	.79

From this table it would appear that the fine-grained rocks give off more gas than those of coarser granularity. One of the reasons for this difference probably lies in the fact that metasomatic changes are favored in fine-grained rocks, whose crystals, being smaller, afford more numerous junction-planes between the crystals, through which solutions more readily traverse the rock than in the coarse-grained varieties. Among other changes, hydration and carbonation should alter fine-grained rocks more effectively than coarse-grained ones.

Fineness of grain in igneous rocks usually means that the lava cooled rapidly, and this would hinder the escape of the inclosed gas. But in the process of slow crystallization, such as produces large crystals and coarse texture, much more of the gas would be likely to be crowded out of the growing crystals. However, as a general rule, fine-grained igneous rocks are surface flows, while coarse-texture types were formed at some depth below the surface, and hence a larger proportion of whatever gas was expelled from the rapidly cooling lavas would be more likely to escape altogether than would

be the case with the gas which was excluded from growing crystals in deeper horizons, as in bathylithic intrusions, where final escape was difficult. In this problem of granularity, as in the matter of age, the quantities of gas evolved are probably determined by a combination of complex factors rather than by any single cause.

RESULTS AT DIFFERENT TEMPERATURES

The different gases are not all expelled from rock material at the same temperature, nor are they evolved at the same rate. In general, hydrogen sulphide and carbon dioxide are not only the first gases to appear, but they are more rapidly given off than the others. Carbon monoxide follows the dioxide as the temperature is raised, and generally increases in relative importance, as the latter begins to subside, toward the end of the combustion. Hydrogen and marsh-gas are most conspicuous at high temperatures, and hence attain higher percentages in the last half of the gas than in the first half. Nitrogen appears to be disengaged with much difficulty, requiring considerable time at a high temperature.

ABSORPTION

Experiments to test the power of gas-absorption by rock material indicated that while a rock powder may take up certain gases while cooling from a high temperature under special conditions, absorption, if it goes on at all at ordinary temperatures, takes place very slowly. However, when rock powders which have apparently been deprived of all their gas were reheated after a sufficient interval of time, there was usually a second evolution of gas. An analysis of the gas from a drill core of Keweenawan diabase from Houghton, Mich., which was kindly furnished by Dr. A. C. Lane, showed 3.88 volumes of gas per volume of rock.[1] After the gas was extracted, the apparently exhausted powder was stored away in a paper bag. Six months later, when reheated, this material yielded 1.92 volumes of gas. From this and other similar experiments it was found that an interval of time partially restores the gas-producing properties of rock powders. For this phenomenon there are two possible explanations. Either, the first heating does not expel all the gas contained in the rock, which, by some sort of diffusion or molecular rearrangement, gradually pre-

[1] Analysis No. 85.

pares itself to come off when again heated; or else the rock powder absorbs gases from the atmosphere. To exclude atmospheric absorption this Keweenawan diabase powder, which originally gave 3.88 volumes, and after six months 1.92 volumes, was heated a third time (a week later) with the evolution of very little gas. This powder, after cooling in the vacuum, was taken out of the combustion tube and immediately placed in a flask filled with freshly distilled water. A stopper being fitted into the flask, it was allowed to stand for three days. At the end of this time, the water was poured off, the powder quickly, but thoroughly, dried, and put into the combustion tube. When heated, this powder gave off .79 volumes of gas, of which carbon dioxide constituted 67 per cent. This carbon dioxide could not have come from the air, but must have existed within the rock material and must have withstood three successive heatings in the combustion tube. This experiment favors the conclusion that the gas which is obtained from a rock powder by a second or third heating after a period of time, is due, not so much to a process of selective absorption from the atmosphere, as to changes which have been slowly taking place within the powder itself.

STATES IN WHICH THE GASES EXIST IN ROCKS

In order to explain the immediate source of the gases obtained by heating rock material in vacuo, three different hypotheses naturally present themselves. The simplest of these is to suppose the gases to exist in minute cavities or pores, having been entrapped within the rock during the process of solidification. This supposition is suggested and supported by the observation that microscopic slides of some minerals, notably quartz and topaz, reveal numerous small gas-bubbles. But while there is evidence that some gas is thus held in cavities, there is equally strong evidence to show that the greater part of it cannot be attributed to this source.

To escape the difficulties encountered by the first hypothesis, appeal is made to the imperfectly understood property of some of the elements to "occlude," or dissolve within their mass, certain gases. It is remembered that under the proper conditions palladium will occlude 900 times its own volume of hydrogen, and that the same gas is also absorbed, in lesser degree, by other metals, particularly plati-

num and iron, while silver has a similar affinity for oxygen. This principle applied to igneous rocks as a hypothetical source of their gases becomes at once a more difficult proposition to prove or disprove.

The third hypothesis, more conservative than either of the others, assumes that these gases do not exist in the rocks in the uncombined, or gaseous state, but are produced in the combustion-tube by chemical reactions at high temperature.

GAS IN CAVITIES

The studies of Brewster, Davy, Sorby, Hartley, and others, have established the presence of gas, generally carbon dioxide, though sometimes nitrogen, in the minute cavities of certain crystals. But while microscopic investigations have indicated that carbon dioxide constitutes more than 90 per cent. of the gaseous matter inclosed in these cavities, and hydrogen is found in traces only, the latter gas is the most important constituent of the mixture derived from rocks by heat. In addition to this, the observation that those rocks which are not known to contain many gas cavities produced several times as much gas as the cavernous quartzes, also suggested that the bulk of the gas, at least, could not be attributed to inclosure in cavities. Moreover, basic rocks were found to be more productive than acidic, whereas it had generally been supposed that the latter, owing to their greater viscosity, should entrap more gas and vapor than the more fluid basic lavas.

The suspicion that the gas did not come from cavities in any large degree was strengthened by the observation that the composition of the gas varied according to the temperature to which the rock powder was heated. If from cavities, the liberation of the gas should commence with a slight rise of temperature, and should continue more or less steadily, as the heat increased, until the expansive force of the gas had burst open most of the pores. Since all gases expand equally, one should burst its confines as soon as another, and a sample of gas obtained at any given temperature should not differ very widely in composition from that evolved at any other.

These and other considerations led me to try a series of experiments which should show how much gas actually could be obtained from the opening of cavities alone. For this purpose a crusher was devised,

which was capable of pulverizing a rock specimen in a complete vacuum. Any gas liberated could then be pumped off and analyzed. Two specimens of basalt, one from the Faroë Islands and the other from Hawaii, gave little or no gas. Vein quartz from Iron County, Utah, gave no trace of gas. Being desirous of finding some specimen which would yield gas when crushed in this manner, I procured some crystals of cavernous quartz from Porretta, Italy, in which several of the cavities exceeded a millimeter in diameter. These, when crushed, yielded carbon dioxide amounting to only .03 of the volume of the quartz. An analysis showed also a little methane and some nitrogen, but the amount of gas available was too small for the determination to be of any value. The result of this last test agrees with the microscopic studies of the early investigators. Carbon dioxide exists in the cavities of quartz, but its volume, compared with the volume of inclosing mineral, is small.

GASES DUE TO CHEMICAL REACTIONS

We may note very briefly the possible sources of gas from high-temperature reactions between the non-gaseous constituents of the rocks.

Hydrogen may be produced at temperatures above 500° through the decomposition of steam by a ferrous compound.

Carbon dioxide is liberated when an ordinary carbonate is heated sufficiently, and hence if the rock specimen be slightly carbonated, gas will be derived from this source and will embarrass the determination of the free gas.

Carbon monoxide is formed from carbon dioxide when that gas is heated in the presence of iron in the ferrous condition, and also to a lesser degree when heated with free hydrogen.

Possible sources for methane are carbides, the decomposition of organic matter, and the reaction between carbon monoxide and free hydrogen which gives marsh-gas and water.

Nitrogen and the sulphur gases may be attributed in part to nitrides, sulphides, and basic sulphates.

Many of these chemical reactions actually took place in the combustion tube during the process of extracting the gas from the rock material, and in some cases the larger part of the gas doubtless was

produced in this way from the non-gaseous constituents of the rocks. But these reactions were, in some instances at least, quantitatively inadequate to produce all the gas obtained. Quantitative experiments upon quartz and beryl indicated a considerable excess of hydrogen over what could possibly be produced from reactions involving the entire weight of iron salts in these minerals. Particularly striking was the case of a beryl from New England which expelled 150 times as much hydrogen as could be assigned to the interaction of steam and ferrous oxide under the most generous assumptions, and 37 times the maximum quantity possible from the total weight of iron in the material if it all occurred either as pyrite or in the metallic state.

OCCLUDED GASES

Such gas as was not held mechanically entrapped within cavities, nor originated from chemical reactions within the combustion tube, is assigned to that imperfectly understood phenomenon to which Graham gave the name *occlusion.* Because the possibilities of obtaining gas from hydration and carbonation are much reduced in the case of freshly fallen meteorites, these bodies in some respects furnish the best conditions for studying the truly occluded gases. To obtain fresh material which had not been subject to hydration and carbonation, a fragment from the Allegan meteorite was obtained from the National Museum. This stone, which was gathered up still hot, within five minutes of its fall, and has not been subjected to outdoor exposure, yielded somewhat more than half of its own volume of gas. Material from the interior of other meteorites yielded even more gas.

In the case of rocks, the amount of occluded gases may be actually greater than that indicated by demonstrating the inadequacy of the other modes of holding gas to account for the total quantity extracted in the laboratory. But a determination of the exact proportion of occluded gas in these cases would be difficult. In general, argon and helium, which do not enter into chemical combination, together with at least as much of the other gases as can be shown not to have been produced by chemical reactions, or the bursting of inclosing walls, are to be attributed to occlusion, or to some form of diffusion not distinguishable from occlusion.

SIGNIFICANCE OF THE THREEFOLD STATE

While chemical reactions and the phenomena of occlusion imply that gas exists in the interior of the earth, the presence of gas inclosed in cavities, under great pressure, adds the further implication that the gas often exceeded the point of saturation of the magma, at least at the stage of solidification. Cavity gases are most abundant in minerals of poorly developed cleavage, pointing perhaps toward a strong tendency to escape along cleavage planes during, or after, crystallization. While most commonly observed in non-cleavable quartz, the gas inclusions in that mineral may owe their abundance to the fact that quartz is generally the last mineral to crystallize out of a magma, and hence such absorbed gases as did not enter into the other crystals would become concentrated in the siliceous residue, and might supersaturate it. It is probably this freely moving gas above the point of saturation which contributes most to the mobility of lavas. Dissolved gases and vapors, while favoring fluidity, would seem to be relatively less effective. However, gases mechanically entrapped in crystalline rocks are quantitatively not very prominent, suggesting that perhaps the theory of liquidity due to gas is overworked. But, on the other hand, it is true that as a lava cooled down to the point where the last mineral crystallized, its gas-solvent powers would be increasing, allowing some of the gas to pass into solution. At the same time, free gas would be occluded by the growing crystals. Experiments upon the re-absorption of gas by exhausted rock powder indicate that a portion of the gas unites chemically as the heat diminishes. Because of these processes, liquid lavas may be supplied with free gas, though the solidified rocks retain but little gas in this condition.

WATER AND HYDROGEN

The reversible reactions involving hydrogen, water, and iron compounds, which cause uncertainties in the extraction of gases by heat, are also operative within the earth. In the laboratory, when either ferrous salts and water, or ferric compounds and hydrogen, are heated in tubes without the removal of the products, reversible reactions set in until a condition of equilibrium is established. Hydrogen and water, ferrous and ferric salts, are all present in a state of balance. In the interior of the earth, the heated, though solid rocks

should, it would seem, behave similarly, though hindered by the slowness of diffusion. Nor should liquid magmas constitute any exception to the law. Both hydrogen and water gas, theoretically, should be present in liquid magmas and heated solid rocks.

For reasons which cannot be discussed here, chemical equilibrium favors the formation of ferrous salts and water, as the temperature increases. Because of this, there is much reason to suppose that, at the depths where lavas originate, hydrogen and oxygen exist combined as water, since up to temperatures of 2,000° C. the dissociation of water takes place only to a limited extent. If a state of equilibrium between hydrogen, water, and the iron compounds were established in the heated interior where a magma originated, as soon as it commenced its way upward and began to lose heat, the condition of equilibrium would be destroyed. With the falling temperature, the tendency to re-establish equilibrium would favor the formation of that system which was produced with the liberation of heat, i. e., magnetic oxide and free hydrogen. In ascending lavas, which are losing heat, the tendency, therefore, is to produce hydrogen and magnetite, or ferroso-ferric compounds. This is doubtless an important source for the hydrogen which is so copiously exhaled during a volcanic eruption. At the same time this process accounts for the widespread occurrence of magnetite in igneous rocks.

In general, these reversible reactions tend to show that it is but a short step from hydrogen to water, and from carbon dioxide to monoxide, and vice versa, and that all of these must occur within the earth owing to the process tending toward equilibrium. Whether hydrogen, in a particular case, occurs in the magmas in the free state, or in the form of water gas, therefore becomes relatively unimportant. Because of this variation of state, the problem becomes more complex and broader in scope. For the most part, these water gases are to be regarded as truly magmatic, and not derived from surface waters penetrating to the liquid lavas. But this is a complex question and cannot be touched here. These water gases are here put forward as essential factors in the evolution of the magmas from the original planetary matter.

The reactions working toward equilibrium are able to supply hydrogen and carbon monoxide under conditions favorable to their

absorption and retention, even if they were not originally present as occluded gases. The sources of the gases obtained from rocks are so complex that it is difficult to determine how much is to be assigned to each. Because of the penetration of surface waters containing carbonic acid in solution, throughout the accessible rocks of the earth's exterior, it is likely that, in many cases, the bulk of the gas obtained by heating powders in vacuo has been derived from acquired water and carbonated compounds. But in fresh meteorites, which presumably have not been subjected to action of this sort, occlusion is relatively more important.

From the constitution of meteorites, some of the principles of early terrestrial evolution may, perhaps, be inferred, though the growth of the earth was probably not quite analogous, in all respects, to the formation of the meteorites. Whether we take the meteoritic material to represent the heavier part of the original matter of the solar system, or the stellar system, as a whole, matters little in the geologic problem. If, in truth, the unoxidized, heterogeneously aggregated material of meteorites be typical of the original heavy material of the earth, it becomes evident that, in the case of our planet, other factors have been at work which are not operative in the bodies of which the meteorites are supposed to be fragments. These visitors from space are characterized by such minerals as cohenite, $(Fe, Ni, Co)_3C$, lawrencite, $FeCl_2$, oldhamite, CaS_2, and schreibersite, $(Fe, Ni, Co)_3P$, which, next to nickel-iron, is the most widely distributed constituent of iron meteorites,[1] though of less importance in the stony specimens. Such compounds imply an absence of both free oxygen and water in notable quantities. Of like import is the absence of hydrated minerals, such as micas and amphiboles. Water and an oxygenated atmosphere appear to be the agents which are lacking in the bodies from which the meteorites were derived, but which have been the operative factors in working over the outer portion of the earth.

But the original source of the earth's atmosphere and hydrosphere is taken to be gas occluded, or absorbed, in the primitive meteoritic material. These original gases, escaping, furnished both atmosphere and hydrosphere when the earth became of sufficient size to retain

[1] Farrington, *Jour. of Geol.*, Vol. IX, pp. 405–7, 525, 526.

them. A self-regulating system was inaugurated. In the early stages of the hydrosphere, when growth by infalling planetesimals was rapid, much water was buried within the fragmental crust. This material, worked over by volcanic activity, brought to the surface and subjected to weathering and erosion, and buried beneath more material, has undergone assortment and alteration until the accessible rocks at the present time are very different from the meteoritic matter. Since the earth attained its growth and the infall of planetesimals slackened, much less water has penetrated to great depths below the surface. Post-Archean sedimentaries have not yet reached thicknesses sufficient to carry inclosed water down to the depths from which the lavas arise. Deep mines indicate that fractures and fissures do not convey water down to very great depths at the present time. If water does not penetrate so rapidly now, and hydration and carbonation are less effective, it is also probably true that subsiding vulcanism brings less gas to the surface.

It is essentially a system of balance. At the same time that water is being buried with sediment, its elements, hydrogen and oxygen, the latter in the form of the oxides of carbon, are exhaled from the earth's interior through volcanic outlets. But the system here suggested is very different from the postulated limited cycle of underground water which, following Daubrée's famous experiment,[1] has crept into geologic literature as the origin of volcanic vapors and the modus operandi of vulcanism. Instead of surface waters following cracks and fissures down to the hot lavas there to be absorbed, the water already is present, and is a part of the rocks and magmas in the interior, whether actually combined as water, or as its elements held in solution, or chemically united in other compounds. These gaseous elements form an integral part in the magmas, having been vital factors in their development from the primitive planetary matter. That this process of reworking has gone on to considerable depths, if we are to start with typical material, is evidenced by the fact that the deep-seated plutonic rocks are characterized by micas and other hydrous minerals, while mineral species of the meteoritic type are absent.[2]

[1] Daubrée, *Études synthétiques de géologie expérimentale*, Tome 1, pp. 236–46.

[2] This statement should perhaps be qualified. The basalt at Ovifak, Greenland, contains iron strongly resembling the meteoric metal, in which the minerals cohenite,

The more restrictive phase of the problem of water will be discussed under the head of vulcanism.

VULCANISM

In the actual dynamics of vulcanism, provided the gases are original in the magmas, the state in which they occur is not of vital importance, except in so far as it determines the conditions under which the gases become free, from occluded or chemical bonds, to perform their part in the mobility of lavas, in the explosions which sometimes accompany eruptions, and in the phenomena of fumaroles and volcanic vents. The distinction between cavity, occluded, and chemically united gas, which is made in the case of solid igneous rocks, cannot be extended to the liquid lavas. In the liquid lava the gas may be supposed to be imprisoned mechanically, or else to form a part of the magmatic solution. On the solidification of the mass, the gas, formerly existing in the free state, may enter chemical combinations at the lower temperature, may be occluded by the solid rock, or may become entrapped within the minerals last to crystallize. So, too, it is possible that some of the gas dissolved in the magma may, because of cooling and crystallization of adjacent portions of the solution, reach a supersaturated condition and appear in the solid rock also as gas inclusions. Otherwise, it would pass into the solid rock occluded or chemically combined. The condition of the gases examined in the laboratory need not, necessarily, correspond to a particular state of occurrence in the lava before crystallization.

Gases mechanically distributed throughout the lava would always be an operative factor in vulcanism, while such gases as were chemically combined in the solution would, presumably, only become free, and hence fully operative, upon the lowering of the temperature and the relief of pressure,[1] and probably but partially then. Since vapors and gases in the free state are the cause of volcanic explosions, they can be traced as far down in the conduits as explosions occur. From the nature of these explosions, which appear to be due to the accumu-

lawrencite, and doubtfully schreibersite have been recognized. The occurrence of this terrestrial iron would indicate that material of this sort still occurs at points within the outer part of the earth.

[1] A falling temperature favors the liberation of hydrogen from water by ferrous compounds (see p. 553), while carbonates are most easily decomposed at low pressures.

lation of vapor gradually working upward until suddenly able to relieve itself, it is fair to suppose that aqueous vapor and the auxiliary gases are present in the free state at still greater depths.

It has been the observation of those who have studied volcanic eruptions that water vapor is by far the most abundant of the gaseous products of volcanoes. Water is also the principal compound of the element hydrogen, which is quantitatively the most important gas obtained by heating igneous rocks *in vacuo*. According to one of the common theories of vulcanism, it is water, circulating underground and necessarily dissolving and absorbing mineral and gaseous material, which penetrates to the lavas and gives to them their supply of vapor and gases. Water, then, is a critical element in the theories of vulcanism, and likely to be a decisive factor upon the basis of which many of these theories may stand or fall. It is, therefore, of great importance to know whether the aqueous vapor, which is so copiously exhaled from volcanic vents and plays such a rôle in vulcanism, is derived originally from the magmas, or is merely underground water which has been incorporated by the lava in its journey upward. A decision of this question will carry with it the solution of the allied question concerning the ultimate source of the other gases, and also throw much light upon some of the more comprehensive theories of vulcanism.

Appealing to the fact that chlorine, in the form of hydrochloric acid and volatilized chlorides, is one of the products of volcanoes, one of the standard hypotheses attributes the cause of vulcanism to the penetration of sea water to the heated interior. If this were so, isolated volcanoes far out at sea would be expected to yield much more chlorine than those on the continents. But the Hawaiian volcanoes exhale comparatively little chlorine or sublimed chlorides. It has been claimed that rain water, sinking into the cone, would have sufficient head to exclude the sea water from the neighborhood of the hot lava. Rain, however, falls upon but a small part of the whole cone, whose greater portion is under the sea. It would seem that if rain water, falling upon a cone built up from the ocean bottom, is able, by means of its head, to keep out the sea water which covers the lower slopes, the same amount of water precipitated upon a continental volcano would be even more efficient in preventing the general underground

water from coming in contact with the lava in the conduit. Whatever may be the reason for the small amount of chlorine given off by the volcanoes of Hawaii, sea water does not reach the heated lavas in sufficient quantities to affect them appreciably.

On account of the pressure exceeding the crushing strength of the rock, pores and crevices cannot exist at depths greater than 30,000 feet according to the most generous estimate,[1] and it is probable that continuous cracks cease much short of this. Beyond this extreme figure, meteoric waters cannot be regarded as of any quantitative importance, on account of the extreme slowness of diffusion through solid bodies not containing minute fractures. Liquid carbon dioxide, still existing under great pressure in sand grains of pre-Cambrian age, is a concrete example of this slowness. While, theoretically, water may extend downward to the limit of the zone of fracture, the testimony of deep mining appears to show that meteoric waters grow relatively scant, as a rule, below the uppermost 1,500 to 1,800 feet of the earth's crust.[2] This shallowness of meteoric water increases the difficulties encountered by the hypothesis that the lava beds are supplied from this source, since they rise from far greater depths and only the upper portions of their conduits would be exposed to these waters. It is in this portion of the zone of fracture that Daubrée's much-quoted experiment upon the Strasbourg sandstone[3] finds its application, if anywhere, since numerous capillary pores with plenty of water are requisites for the operation of this principle. This famous experiment demonstrated that, owing to its force of capillarity, boiling water will pass through a disk of sandstone, 2 centimeters in thickness, against a slight steam-pressure on the other side. But it was only necessary for the steam-pressure to reach 685 millimeters, or nine-tenths of an atmosphere, in order to prevent any more water from passing through the sandstone. It is a long jump from this trivial capillary force, equal to less than one atmosphere of steam pressure, to the great pressures which would have to be overcome in the depths of the earth's crust in order to reach the hot lavas, even

[1] Hoskins, *16th Ann. Rept.*, U. S. Geol. Surv., p. 853.

[2] Kemp, *Economic Geol.*, Vol. II (1907), p. 3; Finch, *Proc. Col. Sci. Soc.*, Vol. VII (1904), pp. 193–252.

[3] Daubrée, *Études synthétiques*, Tome 1, pp. 236–46.

though it be allowed that the water vapor, if it came in contact with the lava, would be absorbed. Capillary force seems quantitatively inadequate.

To reach the critical pressure of water due to the hydrostatic column, it is necessary to penetrate the earth to a depth of about 6,900 feet. At depths less than this, water passing into the vaporous condition, in the neighborhood of hot volcanic conduits, at temperatures below the critical point, should leave behind more or less of the matter held by it in solution, since the condensation, and hence molecular attraction of the vapor for solutes, is less than that of the water. Thus even if vapor from underground waters should enter the lavas, as Daubrée has suggested, in the outer 6,900 feet of the earth's crust, much of the chlorides, sulphates, carbonates, and silicates, dissolved in the water, would have been left behind. At depths between 6,900 feet and 25,000 feet, beyond which water cannot penetrate, owing to the closure of all pores by the pressure of superincumbent rock, mineral matter dissolved in the water would probably still remain in solution when the liquid passed into the gaseous state at the critical temperature, since the density of the gas is equal to, or greater than, that of the liquid.

The lava, being under considerable pressure, may be supposed to occupy all the cracks and crevices in the adjacent rocks, except those of capillary dimensions. If, therefore, in the passage of underground water into vapor, preparatory to entering lavas in the outer 6,900 feet of the earth's crust, much of the dissolved mineral matter be deposited in the minute pores leading to the lava, they should quickly become sealed, preventing any further access, even of water, to the lava. To test this principle experimentally, a cylinder of medium-grained Potsdam sandstone from Wisconsin, 40 millimeters in diameter and 28 millimeters in thickness, was soldered into a short piece of iron piping, fitted at one end with an elbow to serve as a receptacle for water, and at the other with a cork and a condenser. When ready, the receptacle was filled with Lake Michigan water and a Bunsen burner was placed so as to heat the sandstone cylinder within the iron tube. One side of the sandstone was thus kept at a temperature slightly above 100°, while the other face, in contact with the water, remained just at the boiling-point. Water was found to

penetrate the porous cylinder readily, evaporating and leaving its dissolved material within the mass of the sandstone, and escaping as steam on the farther side. The rate at which the water passed through the sandstone at the outset was not determined, but after 5 liters of lake water had been used, it was found that 129 cubic centimeters traversed the rock and were condensed in one hour. The rate slowly fell as the experiment progressed. While the thirteenth liter was being used, only 73 cubic centimeters passed through the sandstone per hour. It was evident that the pores were becoming clogged, but to complete the experiment with Lake Michigan water, which contains only 150 parts of solid matter per million, would have required too much time. To hasten the process, a saturated solution of calcium sulphate was substituted. This soon caused a marked slackening of the passage of water through the rock, and doubtless would have sealed the pores completely, if allowed sufficient time.

From this experiment, it appears certain that water, evaporating in the pore spaces of a rock and escaping as steam, will leave behind whatever material is in solution, until the crevices become clogged and the penetration of water ceases. This principle may be applied to the outer 6,900 feet of the earth's crust; in the superficial portion of this zone it should be very effective, since the conditions more nearly approach those of the experiment; in the lower portion of this belt, as 6,900 feet and the critical pressure (as well as temperature in the neighborhood of hot volcanic pipes) is approached, the density, and hence the solvent powers, of the water vapor approach those of the liquid. Toward the critical point of water, therefore, the application of this principle becomes more uncertain, but it would seem to be operative also at these depths, though more and more slowly as the critical point is neared.

It might be objected that the passage of water into vapor, involving the latent heat of steam, would keep the adjacent rocks cool and cause the deposition to take place at the very contact where the hot lava could fuse, and dissolve, the precipitated salts. But it is very doubtful whether the vaporization of such a small quantity of water, taking place with the slowness imposed upon it by the minuteness of the capillary pores, would keep the contact rocks at a temperature below 365°. The gap between 365° and 1,100° is too great for there

not to be a space, if of a few inches only, at an intermediate temperature. It is also to be remembered that the latent heat of steam diminishes with the pressure until, at the critical point, it becomes zero. The testimony of the country rocks through which a volcanic conduit has passed is that metamorphism has usually progressed to some distance from the contact of igneous intrusion. In a long-established volcano, where the rocks surrounding the conduit have been heated to high temperatures, the deposition of the solutes from any penetrating water should have sealed the capillary tubes and fissures at a distance from the lava such that the latter cannot absorb them and keep the waterway open. Kemp has stated in a recent paper[1] that at the contacts with eruptives, limestone rocks, instead of being porous, are prevailingly dense and compact, and often very hard to drill, as if due to deposition within their interstices. However, the author assigned this supposed deposition to magmatic waters from the intrusion. This brings up a widely established view that magmas, instead of absorbing water from the intruded rocks, give it off, depositing matter in solution to form veins in the zone of fracture.

To quote Van Hise:[2]

> In the belt of cementation, in consequence of the porosity of that zone, the material of the magma, both by direct injection and by transmission through water, may profoundly affect the average chemical composition of the intruded rock for great distances from the intrusive mass.

Geikie cites a case in Bohemia, where certain Senonian marls, invaded by a mass of Tertiary dolerite, begin to get darker in color and harder in texture at a distance of 800 meters from the contact, while, as the intrusive mass is approached, the interstratified beds of sandstone have been indurated to the compactness of quartzite.[3]

But considering only meteoric waters at depths greater than 6,900 feet, where water remains liquid up to the critical temperature, it is less probable that the pore spaces will be filled up in this manner. Nor does it seem likely that Daubrée's theory that water may penetrate rocks against a steam-pressure can operate at these depths,

[1] Kemp, *Economic Geol.*, Vol. II, p. 11.

[2] Van Hise, *Monograph 47*, U. S. Geol. Surv., p. 714.

[3] Hibsch, cited by Geikie, *Textbook of Geology*, Vol. II, p. 774.

since that principle is dependent upon a marked difference between the capillarity of water and of steam, while at the critical point, the density of water-gas being the same as that of water, this force should be absent. The problem then becomes a question of equilibrium between the hydrostatic column of water and that of the lava, in which the pressure of the lava at a depth of 7,000 feet should be in the neighborhood of 2.7 times that of the water, though this preponderance steadily diminishes as the water-gas becomes condensed, with increasing depth, at a rate higher than lava. Whether under these conditions lava can absorb water-gas, is an open question.

Water can only penetrate from 25,000 to 30,000 feet below the surface on account of the closure of all crevices by pressure. But on the assumption that the temperature gradient in the outer part of the earth's crust is 1° C. for each 100 feet of descent (which is probably too high) the critical temperature will not be reached, except in the neighborhood of volcanic intrusions, until at a depth of about 36,000 feet. Hence, over the greater part of the earth, water will remain in the liquid state as far down as fractures and fissures will allow it to seep, and no appeal can be made to the more rapid and potent gaseous diffusion to carry it beyond 30,000 feet. But because of their heat, lavas must originate at much greater depths below the surface, and hence far beyond the reach of surface waters, which can only come in contact with them, and only doubtfully then, in a very limited portion of the throat of the volcano.

These considerations seem to indicate that, for the most part, the volcanic gases and vapors have not been supplied to the lavas by ground waters, but are original constituents of the magmas. Doubtless at the beginning of an eruption, following a period of quiescence, much of the steam merely comes from such rain water as may have accumulated in the crater and upper part of the cone, but this does not account for the gaseous emanations from the lava itself, nor from those volcanoes, such as Stromboli, and the well-known Solfatara near Naples, which maintain a mild form of eruption for long periods. Such meteoric water could contribute to the volcanic gases little except some dissolved air, together with a trace of carbon dioxide, and perhaps hydrogen from chemical action. Such soluble salts as this water might dissolve from the crater walls were brought up from the

interior in the first place (making some allowance, however, for weathering), and so have little bearing on the case.

The hypothesis that the gases and vapors are originally from the magmas is greatly strengthened by the volcanic activity in the moon, if, as is rather generally believed, the great pits on the surface of the moon are craters produced by volcanic explosions; if not, of course the argument does not hold. The gases and vapors which caused the tremendous outbursts cannot be ascribed to the penetration of surface waters and gases, for the moon has neither appreciable atmosphere nor hydrosphere, and, according to Stoney's doctrine, never could have held either, owing to its feeble gravitative control. Such gases as are implied by these explosions must be supposed to have arisen from within the interior of the moon. The extent of this explosive lunar vulcanism, in the absence of any appreciable atmosphere or hydrosphere, furnishes a strong argument against the belief that surface waters and atmospheric gases are essential factors in terrestrial vulcanism.

Thus far evidence of a negative nature has been brought forward to show the difficulties in the way of thinking that surface waters play a prominent rôle in volcanic phenomena. But more positive evidence can be presented to support the view that the hydrogen and water in the deep-seated rocks are truly magmatic. Micas are prominent constituents of the plutonic rocks. The immense granitic bathyliths, which were probably formed beyond the reach of ground waters, are characterized by this group of minerals. In fact, micas are more abundant in the deep-seated rocks than in the surface lavas of similar composition. Yet all micas contain hydrogen (or hydroxyl) and yield water upon ignition. This varies with the mineral species and locality, ranging up to 4 or 5 per cent. If these micas in the massive intrusions are primary minerals, as they seem to be, and were out of the reach of ground waters until long after they were crystallized, there appears no other alternative than to consider this hydrogen as inherent in the magma itself. The general petrological principle that plutonic rocks are micaceous and hornblendic, while their more superficial equivalents are more frequently characterized by pyroxenes which are less hydrous, may point toward the suggestion that the magmas originally contain considerable water or the elements which

can produce it, but as they approach the surface much of the hydrogen and water vapor escapes and pyroxene minerals crystallize instead of these hydrous micas.

All of these facts and deductions lead to the general conclusion that our surface waters have been derived from the interior of the earth, and oppose the idea that to explain the presence of hydrogen, or water, in magmas and rocks, we have merely to appeal to the penetration of surface waters. The meteoric waters are limited to their superficial place and function, both in the evolution of magmas and in vulcanism; an ultimate source is found for these waters; and a steady supply of water and gases is furnished to the earth to offset the loss of vapor into space, and thus contributes to the globe one of the factors necessary to a long period of habitability for living organisms.

VOLCANIC GASES

The gases which escape from fumarolic vents are in many respects similar to those obtained by heating igneous rocks *in vacuo*, but with the addition of oxygen and vapors of chlorides, fluorides, boric acid, and other high-temperature volatilizations. Though nitrogen is much more conspicuous in the analyses of volcanic gases than in those from rocks, this is doubtless due, in the main, to a mixture with atmospheric air. However, the greater heat of the volcano would also favor a higher proportion of nitrogen, as shown by my experiment. Much of the oxygen also is probably from the air. But an analysis of gas escaping from a stream of lava flowing on the sea bottom at Santorin gave Fouqué: oxygen, 21.11 per cent.; nitrogen, 21.90 per cent.; and hydrogen, 56.70 per cent.[1] This would suggest that the dissociation of water also contributes free oxygen.

Fouqué's studies at Santorin confirm the law of variation in composition of volcanic gases, first established by Sainte-Claire Deville,[2] namely, that the nature of the gas evolved depends upon the phase of volcanic activity. Hydrochloric acid, with free chlorine and fluorine, is given off only from the hottest fumaroles where the heat is sufficient to liberate these gases from chlorides and fluorides. At less active vents, sulphur dioxide is the most noticeable of the corrosive gases, while the cooler fumaroles exhale chiefly hydrogen sulphide, carbon

[1] Fouqué, *Santorin et ses éruptions*, p. 230.

[2] Sainte-Claire Deville, *Ann. de chim. et phys.*, 52 (1858), p. 60.

dioxide, and nitrogen. Carbon dioxide and nitrogen escape from all the fumaroles. Fouqué found that the relative importance of hydrogen increased with rise of temperature, and that his marsh-gas (which, owing to an imperfection in the method of analysis in 1867, may have been carbon monoxide, or a mixture of carbon monoxide and marsh-gas) diminished as the activity increased. These observations are entirely in accord with the results of my differential temperature experiments with rock powders. Hydrogen sulphide and carbon dioxide are the gases expelled from the rocks at the lowest temperatures; carbon monoxide and marsh-gas appear at intermediate temperatures, while hydrogen is most prominent when the heat is carried to bright redness. Nitrogen is most abundantly liberated at red heat; hence the presence of that gas at the cooler vents and fissures is chiefly due to atmospheric air.

While carbon dioxide escapes from all fumaroles in greater or less degree, it is at those vents whose activity has subsided beyond the point where hydrogen and the noxious gases are evolved that this gas is most conspicuous. For this reason, carbon dioxide has come to be regarded as marking the dying-out of the volcanic activity. A source for carbon dioxide after the disappearance of the other gases has been sought in the neighboring limestone formations, either from baking or from the chemical action of halogen or sulphur acids. The obvious difficulty confronting this conception is that limestone is not always present to furnish carbon dioxide. Experiments show that below 400° C. carbon dioxide is the principal gas evolved from rock material, and as the lava solidifying in the crater, or conduit, has not lost all its gas, it is only a part of the natural sequence of events that the escape of carbonic anhydride from the cooling lavas should continue for some time after the volcano has settled into quiescence. Some of this carbon dioxide doubtless also comes from previous lavas which, warmed again by the fresh lava, give up some of the carbon dioxide which my experiments show them to contain.

GENERAL RELATIONS

RELATIVE TO THE HYPOTHESIS OF A MOLTEN EARTH

These studies show that, within the range of temperature employed, heat causes the expulsion of gases in whatever form they are held, and

that the greater the degree of heat the more quickly and completely the gases are given off. There is reason to believe that this principle applies to the molten state as well as to the solid condition. If it be applicable to liquid lavas, it would favor the belief that a molten globe would have boiled out most of its gaseous matter before solidifying. Gases near the surface should escape rapidly. It might, perhaps, on first thought, be held that, while much of the gas in the outer portion would be lost, that existing in the central part of the sphere would be retained and slowly recharge the peripheral portion after a crust had formed and prevented further escape; but the molten globe, by hypothesis, grew up gradually, and essentially every part was once superficial. Even today, in an essentially solid earth, there are movements of lava that bring up gases from unknown depths, and it is reasonable to suppose that the molten sphere was stirred up by still more effective convection currents which facilitated the expulsion of gases and vapors, and that almost all of the gaseous material of the globe would have been boiled out before solidification set in.

The complete validity of this view depends much upon the fate of the gases after they have reached the surface. It they were retained in the form of a dense atmosphere, a condition of pressure-equilibrium might be established between the atmosphere and the gases in the liquid earth, by means of which the latter would retain some appreciable amount of gas. But if, as some believe, our atmosphere is about all that the earth can control,[1] the gas expelled from the molten sphere in excess of the mass of the present atmosphere would escape and be lost to the planet. Geological evidences—early Cambrian glaciation, Paleozoic periods of aridity, and the general testimony of life—all point toward the conclusion that early terrestrial atmospheric conditions were not radically different from those of today. If the hypothesis of a heavy atmosphere be not permissible, it becomes very difficult to explain the presence of original gases and gas-producing compounds in plutonic rocks on the basis of the Laplacian or other hypotheses that postulate original fluidity.

RELATIVE TO THE PLANETESIMAL HYPOTHESIS

After the gaseous matter of the ancestral sun was shot out from the solar surface to form the two arms of the spiral nebula, as postu-

[1] R. H. McKee, *Science*, Vol. XXIII (1906), pp. 271–74.

lated by the planetesimal hypothesis, the rock-producing portion is supposed either to have aggregated into planetesimal bodies, or to have been gathered, molecule by molecule, into the nucleus of the earth. The planetesimal bodies gathered in gas molecules of the atmospheric class both by chemical union and by surface adhesion or occlusion. As the earth grew by sweeping in the planetesimals, whatever gases they contained became entrapped in the body of the growing planet and well distributed throughout its mass. At first, the gravity of the earth may possibly have been able to hold only the gases brought in by planetesimal aggregates of rock material and those that became impounded in it by impact, but at a later stage, when increased mass enabled it to hold gaseous molecules, gases may have been added to the atmosphere directly from the nebula, and these, by chemical reactions, may have become united with the surface rocks. As soon as vulcanism commenced, a system of exchange was set up. While gases were being fed to the atmosphere by volcanic action, water, carbon dioxide, oxygen, and nitrogen were being buried with the surface rock material, partly by chemical union and partly by mechanical entrapment, as the growth by infalling matter continued. It is thus quite easy to understand how the earth came to be affected by these gases throughout its mass, and how they came to exist there in all available forms of retention.

While the carbon monoxide and methane derived from rocks by heating *in vacuo* are doubtless chiefly produced from the carbon dioxide and water present in the rock material, there seems good reason to suppose that similar reactions took place within the earth, as the surface material became buried and heated, and hence that carbon monoxide and methane exist, as such, in the earth's body, and are to be reckoned among the natural gases of the rocks.

RELATIVE TO ATMOSPHERIC SUPPLY

The fact that many of the igneous rocks are able to yield hydrogen from reactions between water and ferrous compounds, at high temperatures, indicates that the material of the earth's crust is in a condition of partial oxidation only. Near the center of the earth there is probably very little oxygen, and even up to the surface, barring the weathered mantle, the rocks are suboxidized. Yet the earth is surrounded by an oxygenated atmosphere. Since oxygen is not devel-

oped in the combustion-tube, and does not appear to exist as a free gas in igneous rocks, it is not likely that this constituent of the atmosphere has come directly as an exudation from the interior of the globe. It is to be sought, rather, in a dissociation or decomposition of compound gases by physical or organic agencies. Originally, enough oxygen was derived from water vapor, by physical means, to permit the beginning of plant life; after vegetation appeared, an abundant source of oxygen was found in the carbon dioxide.

The average gas content of igneous rocks, as determined by the analyses now made, may be used to test the competence of the rocks to yield the present atmosphere. Taking the average volume of nitrogen per volume of rock to be 0.05, which is probably nearer the truth than the figure 0.09 given in table 8[1] (owing to leakage of air), it would require the liberation of all the nitrogen in the outermost 70 miles of the earth's crust to produce the nitrogen in the present atmosphere. For an estimate of the amount of igneous rock necessary to yield the carbon dioxide which is now locked up in limestone and coal deposits, we may take Dana's figure of 50 atmospheres of this gas, and an average of 2.16 volumes of carbon dioxide per volume of rock. To produce these 50 atmospheres of carbon dioxide, it is found that a thickness of 66 miles of crust would have to be deprived of its carbon dioxide[2]—a figure which corresponds fairly well with the estimate for nitrogen. If the water of the rocks be placed at 2.3 per cent., a depth of 70 miles would supply the hydrosphere.

On the planetesimal hypothesis, gas has been supplied from the interior to the atmosphere ever since an early stage of the earth's growth, probably from the earliest stage at which an atmosphere could be held, which may be placed at the time when the earth's radius was about 2,000 miles. From this it appears that only a small fraction of the full gas-producing possibilities of the rocks of the earth was required to supply the atmosphere. The fact that gases are still being given forth through volcanoes, and that the ejected lavas still have gas-producing qualities, makes it clear that all the resources of the interior are not yet exhausted. The working qualities of the planetesimal hypothesis, therefore, do not seem to be found wanting in either past possibilities of supply, present output, or prospective reserve.

[1] *Ante*, p. 545.

[2] The limestones, of course, are not here included.

THE SOLIDIFICATION OF ALLOYS AND MAGMAS

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In this consideration of possible analogies in the solidification of alloys and igneous rocks, the treatment will be from a knowledge gained in the study of alloys, and with a confessed ignorance of the subject from the viewpoint of the geologist.

That the value of the views to be advanced is clearly recognized, and that their applicability extends beyond the limited sphere with which the writer is familiar, is well shown in the following extracts from the writings of Dr. George F. Becker,[1] of the United States Geological Survey. He says,

> In a plan submitted to the director when the new physical laboratory of the survey was first contemplated, I laid special stress upon the study of isomorphism and eutexia.

Also,

> It would appear that the relation between liquids must be reducible to very general groups. Liquids must be either miscible or immiscible, and miscible liquids must exhibit either isomorphic properties or eutectic ones.

And again,

> The applicability of eutexia to rock-classification depends upon the fact that it makes the systematic discussion of magmatic mixtures possible. Inasmuch as the subject-matter of lithology consists of mixtures, their classification must be carried out in terms of definite or standard mixtures, while the only mixtures possessing appropriate distinguishing properties are the eutectics. Thus in dealing with magmas or other heteromorphous miscible liquids, the eutectics seem to afford not only the best but the only natural and rational standards of reference. With any eutectic as a basis, a series of magmas may be prepared, each differing from the eutectic by containing an excess of one or more constituents.

Here, then, is the key to the whole discussion—the comparison of alloys and igneous rocks from the standpoint of isomorphism and eutexia, a standpoint which has its rational foundation on the laws

[1] Day and Allen, *Isomorphism of the Feldspars* (Publications of the Carnegie Institution). Introduction by Dr. George F. Becker.

of physical chemistry, more especially the theory of solutions and the phase rule of Gibbs. The application of these laws is of very recent date. In fact, it is hardly necessary to go back more than ten years to cover the period of their development. Because of this fact the drawing of well-worked-out analogies is very difficult; a considerable amount of investigation has been done with the simpler alloys, but in geology the field is practically barren. It will be necessary, therefore, to confine the discussion to the fundamental types of solidification from the viewpoint of their solubility relations, and to point out the application of these laws to certain alloys, and analogous minerals and rocks, wherever possible; leaving to the judgment and imagination of the reader the possibility of their further application to geological problems.

Proceeding from this viewpoint, it is at first essential to grasp a few fundamental facts. Alloys are solutions, and obey the same laws in freezing as aqueous solutions of salts do in crystallizing. It is merely a question of fluidity at a different range of temperature. Not only is this true, but it is likewise true that solubility is not limited to any particular state of the interacting substances. Thus we may have solubility in the solid state, or solid solutions. This is shown in the tendency for mutual diffusion of solid gold and solid platinum; or more well known, perhaps, in the harveyizing of armor plate, where carbon is absorbed by iron at temperatures well below the point of fusion. These solid solutions you are more familiar with as isomorphous mixtures or mixed crystals.

COOLING-CURVES

In obtaining the solubility curves for salts in solution, the usual procedure is to make analyses of the saturated solution at various temperatures, and in this way to obtain a series of points which may be plotted into a temperature-composition curve. In the case of alloys, this method is not so well suited, since we are working at higher temperatures; also we often have to deal with changes in the solid, as well as in the liquid state. For alloys we obtain the necessary data for individual mixtures by means of the cooling-curve, a curve which is a function of time and temperature, and shows the change in the rate of cooling as the temperature is lowered. Breaks in the

curve or changes in direction indicate an evolution or absorption of heat, and denote a change of state or a transition in the substance. In practice, the general method is to heat a metal or alloy of known composition to a desired temperature, introduce a pyrometer, and record the temperature at stated time-intervals during cooling.

Such curves are shown in Fig. 1. The one on the left represents the cooling of pure platinum. Temperatures are plotted on the ver-

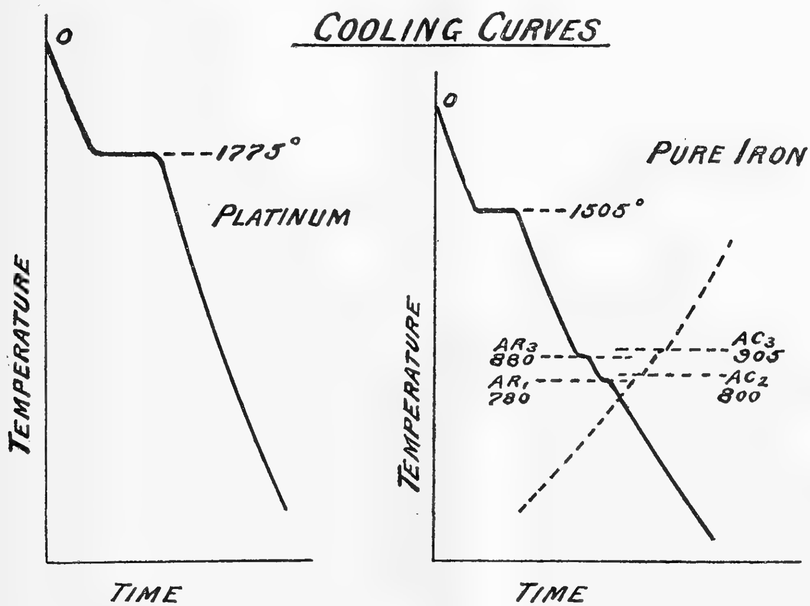

FIG. 1

tical axis, and time on the horizontal. Starting at o, our metal cools gradually, until we reach 1,775°. Here we have a jog in the curve, an arrest in the temperature change due to the freezing of the metal and the evolution of the heat of solidification. Freezing completed, the material cools to room temperature without further break in the curve.

On the right we have another cooling-curve, that of pure iron. Starting again at o, the metal cools to 1,505° when there is a break due to the solidification. On further cooling, we note a different condition from that observed in the case of platinum. There are

two other jogs in the curve, at 880° and 780°, denoting changes in the solid state. These represent the transition points of the three allotropic modifications of pure iron, and are designated as the α, β, and γ states. These allotropic states represent changes in the properties of the iron without change of composition, and are analogous to some cases of pleomorphism in minerals; for example:

$$\text{Sulphur}\left\{\begin{array}{c}\text{orthorhombic}\\ \text{to}\\ \text{monoclinic}\end{array}\right\}96^\circ \qquad \text{Leucite}\left\{\begin{array}{c}\text{pseudo-isometric}\\ \text{to}\\ \text{isometric}\end{array}\right\}500^\circ$$

FREEZING-POINT CURVES

In the investigation of alloys, we consider three general types of solubility relations; with complete miscibility in the molten state it may after solidification be complete, partial, or nil.

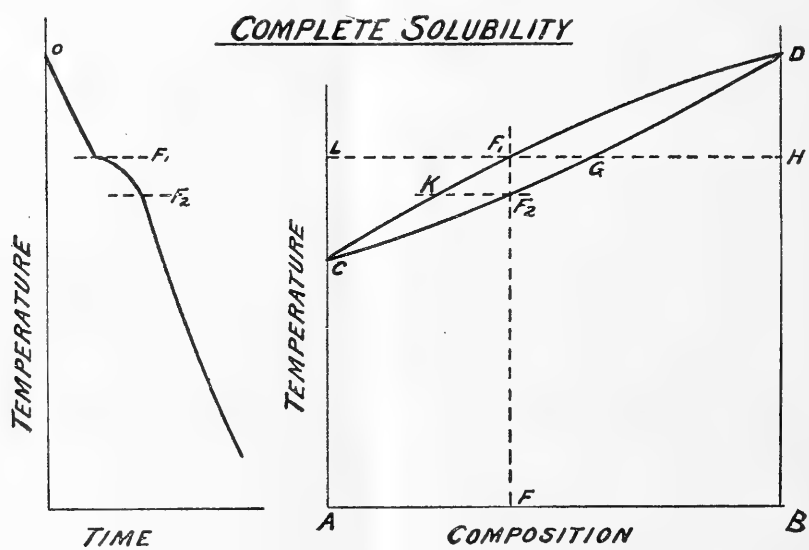

FIG. 2

Referring to Fig. 2, we have represented the type of complete solubility before and after solidification. On the left is the cooling-curve for a single mixture. We note two breaks, at F_1 that due to commencement of solidification, and at F_2 a change of direction due

to its completion. With points for commencement and completion of solidification obtained from similar cooling-curves representing a complete series of mixtures, we may plot a new diagram with the composition on the X axis, and the corresponding freezing temperatures on the Y axis, and obtain the solubility curve as shown on the right of Fig. 2. In metallography this is usually designated the "freezing-point curve." CF_1D and CF_2D are the loci of the upper and lower transition points as obtained from the cooling-curves, and represent, therefore, the commencement and completion of solidification for the entire range of mixtures.

With this type of freezing, a mixture of composition F, for example, will commence to solidify at F_1 with a separating-out of the first frozen particle of composition G, a consequent relative enrichment of the molten metal in element A, and a lowering of the temperature of solidification. During freezing, therefore, the temperature-composition locus of the molten material will shift along the upper curve from F_1 toward C, and that of the solid material along the lower curve from G_1 toward C. If cooling is sufficiently slow because of the complete solubility in the solid, the equilibrium is completed by the diffusion of the different solid particles until finally the resultant alloy has a uniform composition F_2 the same as the original molten mixture.

With complete solubility, therefore, the freezing is selective but not rigid, and the initial heterogeneousness is effaced by diffusion. Under the microscope, the structure should be uniform throughout if diffusion is complete.

Of this type are the Sb-Bi, Ag-Au, Fe-Mn alloys.

The type of complete insolubility is shown in Fig. 3. On the left is the cooling-curve, with a break at K_1, indicating commencement of solidification, and a jog K_2K_2 denoting completion of freezing at a constant temperature. At the right is the freezing-point diagram, with FE_1G and CE_1D as the loci of commencement and completion of solidification. A mixture of composition K will commence to freeze at K_1. The solid separating out will be element A only, because of the complete insolubility; there will be a relative enrichment of the molten solution in B, and a gradual shifting of the temperature composition range from K_1 to E_1. At E_1 the whole of the

remaining solution will freeze at this constant temperature; but because there is no solubility in the solid A and B will separate.

For a mixture of composition E, freezing will occur throughout the mass simultaneously, with a separation in the solid state of A and B. In like manner, for alloy M, freezing will be as explained above, except that element B will first separate out, with a gradual enrichment of mother metal in A, and a gradual lowering of the freezing temperature, until at E_1 there will again occur the isothermal solidification of the remaining solution, with separation of A and B.

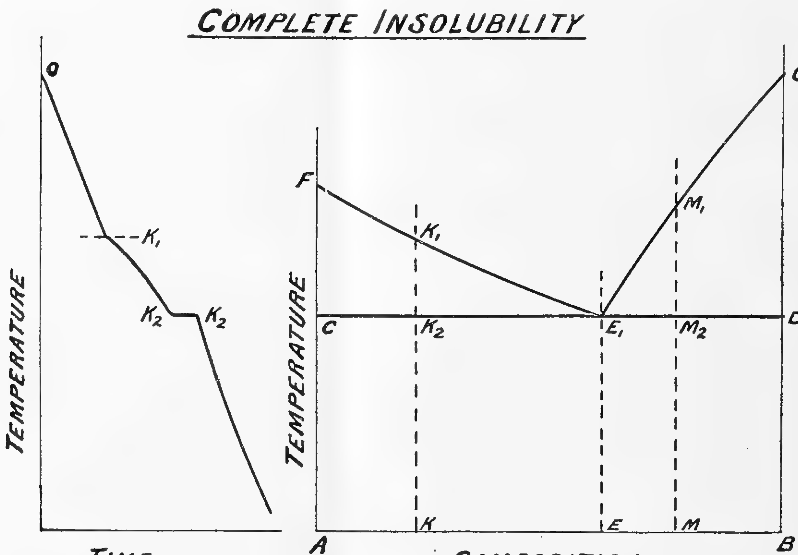

FIG. 3

The point of lowest freezing temperature E_1 is called the eutectic point, and the mixture of this composition, the eutectic mixture, or the eutectic.

Summarizing, we have in this type rigidly selective freezing, with alloys eutectiferous throughout the range of composition, and no tendency for mutual diffusion. Under the microscope we should expect to find a more or less segregated excess metal A or B, depending upon whether the initial composition was above or below the eutectic ratio; together with an intimate composite structure of A and B as the eutectic.

Of this type are the Sb-Pb, Pb-Sn, Cd-Zn alloys.

A third type of freezing-point curve is that of partial-solubility solid, as shown in Fig. 4. This condition is really a combination of the two types previously described. For mixtures between *JF* and *GK*, freezing will be of the type of complete solubility. Between *F* and *G*, the freezing will be selective, as in the complete insolubility type, except that, since there is partial-solubility solid, the excess metal to separate out will be saturated with the other element; and

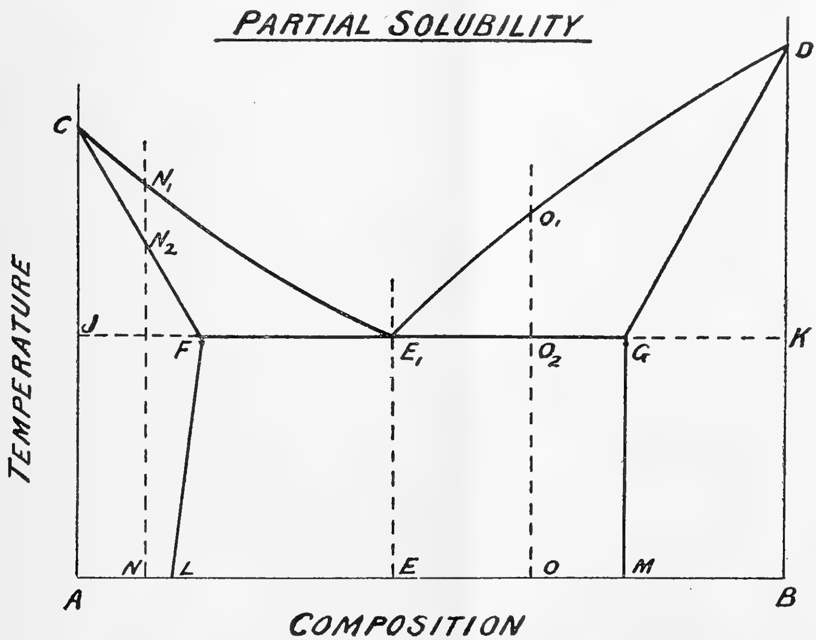

FIG. 4

the eutectic will be a composite of *A* saturated with *JF* per cent. of *B* and *B* saturated with *GK* per cent. of *A*.

With this type of freezing, therefore, we have freezing with complete solubility at the two ends of the series, and under the microscope we should find a homogeneous structure. For the intermediate mixtures there will be selective freezing and under the microscope we should expect a heterogeneous structure of an excess substance either *A* saturated with *B* or *B* saturated with *A*, depending upon

whether the composition of the original molten mixture lay to the left or right of the eutectic ratio; and a composite eutectic A saturated with B and B saturated with A.

Of this type are the Sn-Zn, Au-Ni, Ag-Cu alloys.

Besides these three general types of solubility which we have considered, numerous others could be taken up in detail. For example, A and B might form one or more definite compounds, which compounds could have with A and B and with each other, independently different solubility relations. Or again, there might be only partial solubility while the alloy was still molten. However, all are really combinations and elaborations of the fundamental types to fit more complicated conditions.

ISOMORPHISM OF FELDSPARS

Referring now to one of the few investigations in this line which have been carried out in geological research, we have (Fig. 5) the

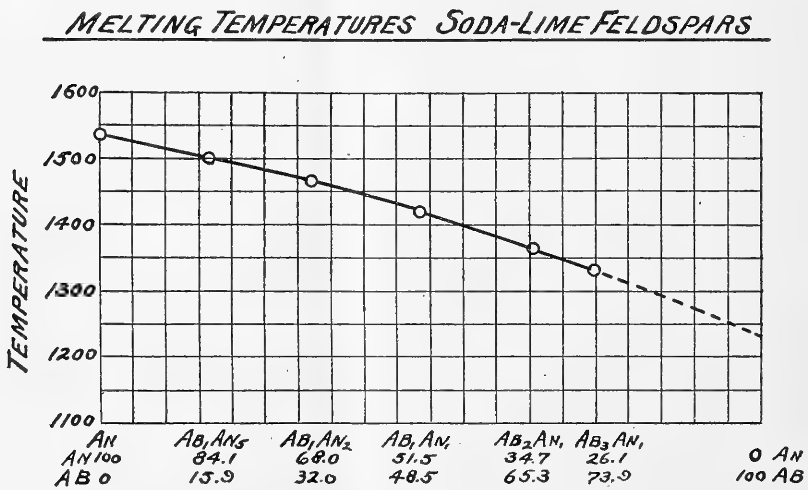

FIG. 5

freezing-point curve of the soda-lime feldspars, as determined by Day and Allen[1] at the Geophysical Laboratory of the Carnegie Institution. The work was conducted exactly as indicated for alloys, by time-

[1] Day and Allen, *Isomorphism of the Feldspars* (Publications of the Carnegie Institution).

temperature records of the desired mixtures. Because of the undesirable supercooling, Day and Allen, however, recorded the heating, rather than the cooling, curve. As will be seen from the diagram, it is of the complete solubility type, with no indication of eutectics or intermediate compounds. It is conclusive evidence that between 100 per cent. of anorthite and 100 per cent. of albite we have an isomorphous series; and microscopic examination was entirely confirmatory.

IRON-SILICON ALLOYS

Fig. 6 shows the freezing-point curve of the iron-silicon alloy,[1] chosen because it represents a rather complex set of conditions. At

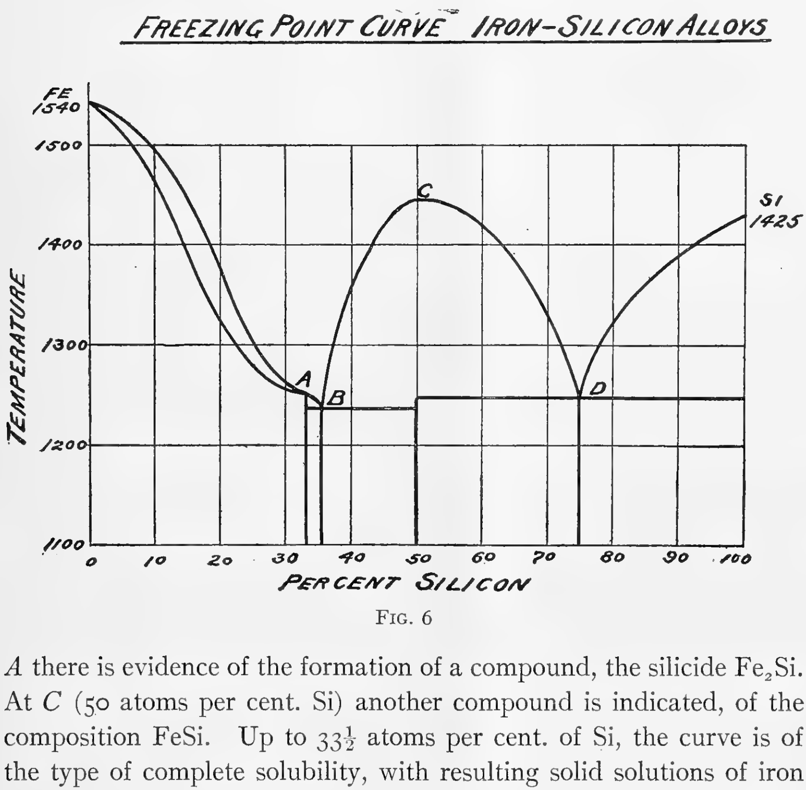

FIG. 6

A there is evidence of the formation of a compound, the silicide Fe_2Si. At *C* (50 atoms per cent. Si) another compound is indicated, of the composition FeSi. Up to $33\frac{1}{2}$ atoms per cent. of Si, the curve is of the type of complete solubility, with resulting solid solutions of iron and Fe_2Si. Between $33\frac{1}{2}$ and 50 per cent., Fe_2Si and FeSi are immis-

[1] W. Guertler and G. Tammann, "Ueber die Verbindungen des Siliciums mit dem Eisen," *Zeitsch. f. anorg. Chemie,* 1905.

cible, and we have completely eutectiferous freezing. This is also the case between 50 per cent. and 100 per cent. Si, with the two components FeSi and Si.

CALCIUM AND MAGNESIUM METASILICATES

Strictly analogous to this is the diagram (Fig. 7) of solidification of calcium and magnesium metasilicates, also determined at the Geo-

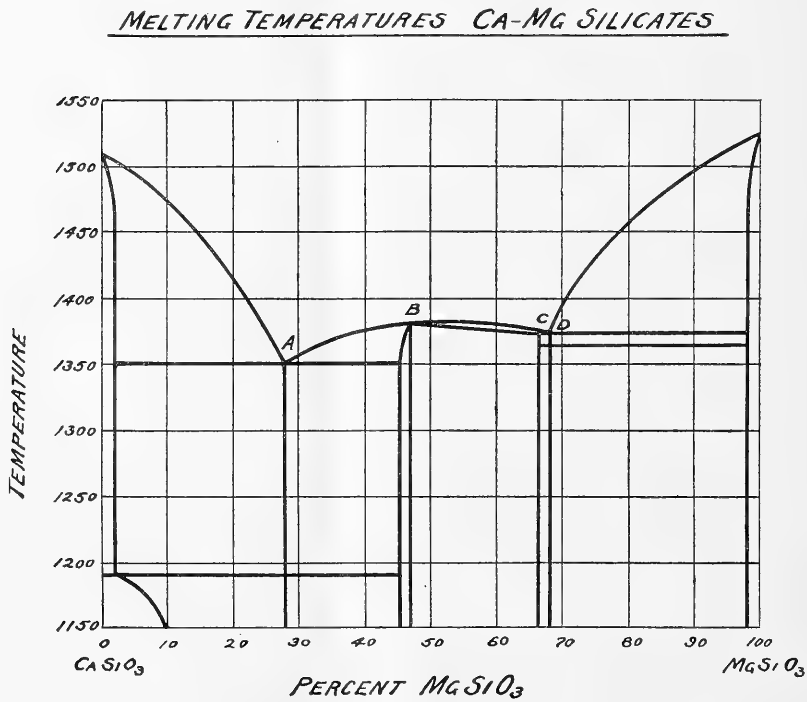

FIG. 7

physical Laboratory of the Carnegie Institution by E. T. Allen and W. P. White.[1] As will be seen, at 47 per cent. $MgSiO_3$ + 53 per cent. SiO_3 there is indication of the formation of the compound $MgSiO_3$ $CaSiO_3$ the mineral diopside. This diopside breaks the diagram into two parts each of the partial-solubility type. For the left-hand side,

[1] Allen and White, "Diopside in Its Relations to Calcium and Magnesium Metasilicates," *Am. Jour. Sci.*, January, 1909.

solid solutions of $CaSiO_3$ and diopside will separate out between 0 and 2 per cent. and 46 and 47 per cent. of $MgSiO_3$. From 2 per cent. to 46 per cent., the structure will be a composite eutectic of $CaSiO_3$ + diopside, each saturated with a small amount of the other, and an excess substance of $CaSiO_3$ or diopside, each saturated with the other, depending upon whether the composition is below or above the eutectic composition of 28 per cent. $MgSiO_3$.

Likewise for the right-hand half of the diagram, isomorphous mixtures of diopside and $MgSiO_3$ are indicated between 47 and 67 per cent. and 98 and 100 per cent. of $MgSiO_3$. Between 67 and 96 per cent. a eutectic will form of $MgSiO_3$ and diopside each saturated with the other, and an excess substance diopside below the eutectic composition of 68 per cent. of $MgSiO_3$, and $MgSiO_3$ above this ratio. This diagram also furnishes an example of a condition frequently met with in alloys, that of allotropy, or transitions below the solidification range. Thus above 1,190° the α $CaSiO_3$, or pseudo-wollastonite, is the stable form, but is unknown in nature; below this temperature the β form, the mineral wollastonite, is stable. With $MgSiO_3$ the β form is magnesian pyroxene occurring in meteorites and intergrowths with enstatite. At 1,365° this is transformed into the orthorhombic α form distinct from enstatite and unknown in nature.

Microscopic examination confirmed these deductions except that the eutectic texture was rarely met with, probably due to the very slow cooling and consequent segregation of the constituents.

EUTECTICS AMONG ROCKS

Work of this general nature, but not so reliable and accurate, has been done by J. H. L. Vogt on the silicates, and he mentions a number of eutectic mixtures, as follows:

68 per cent. diopside	with	32 per cent. olivine
74 per cent. melilite	"	26 per cent. olivine
65 per cent. melilite	"	35 per cent. anorthite
40 per cent. diopside	"	60 per cent. akermanite
74.25 per cent. anorthite	"	25.75 per cent. quartz
75 per cent. albite	"	25 per cent. quartz

THREE COMPONENT MIXTURES

So far the discussion has been confined to the freezing of two component mixtures. However, more generally, particularly in

rock magmas, three or more constituents will be present. This greater number of components will admit of the possibility of greater multiplication of the solid phases forming and results in a very much more complicated problem. Unfortunately, there have been published the results of but very few investigations along this line, and these only for very simple cases. To represent the equilibrium of a three-component mixture we make use of the property of an equilateral triangle that if from any point within perpendiculars be dropped upon each of the three sides, the sum of the lengths of these perpendiculars is a constant, and equal to the altitude of the triangle. Consequently with an equilateral triangle as a base, each apex of which represents respectively 100 per cent. of *A*, *B*, and *C* constituents, and temperatures plotted perpendicular to this base, we obtain a space-model, with the equilibrium between the solid and liquid phases, or, in other words, the locus of the solidification points of each particular mixture, represented by a set of warped surfaces, very much as topography is represented on a relief map. And just as we represent the elevations of this relief map on a plane surface by means of contour lines of equal elevations, so do we represent the temperatures of our space-model of solidification, by contour lines of equal temperatures, or, as technically called, by isotherms.

Such a representation is shown in Fig. 8, for the solidification of the Bi, Pb, Sn alloys.[1] These have the simplest relations for a three-component alloy, since no intermediate compounds are formed, and there is complete insolubility between the constituents. The dotted lines are the isotherms for the commencement of solidification. The altitudes at each angle denote 100 per cent. of each of the elements Pb, Bi, and Sn. The triangle is divided into three regions by the lines *GE*, *IE*, and *HE*, which correspond to our previous freezing-point loci representing the primary separation of one of the three pure components. Consider an alloy of composition *A*. The point denoting this alloy lies in the region Bi, *GEI* on the isotherm 175°. At this temperature, therefore, pure bismuth commences to separate out. The alloy becomes successively poorer in bismuth as the temperature is lowered, and, since the ratio of tin to lead must remain

[1] G. Charpy, "Study of the White Alloys Called Antifriction," *Metallographist*, Vol. II, 1899.

constant, the composition shifts along the line *AC* from *A* to *C*. At 125° we meet the line *IE*. At this temperature, therefore, a binary eutectic mixture of bismuth and tin now separates out and the composition of the mixture is displaced along the line *IE* until finally at point *E* corresponding to a temperature of 96°, the ternary eutectic

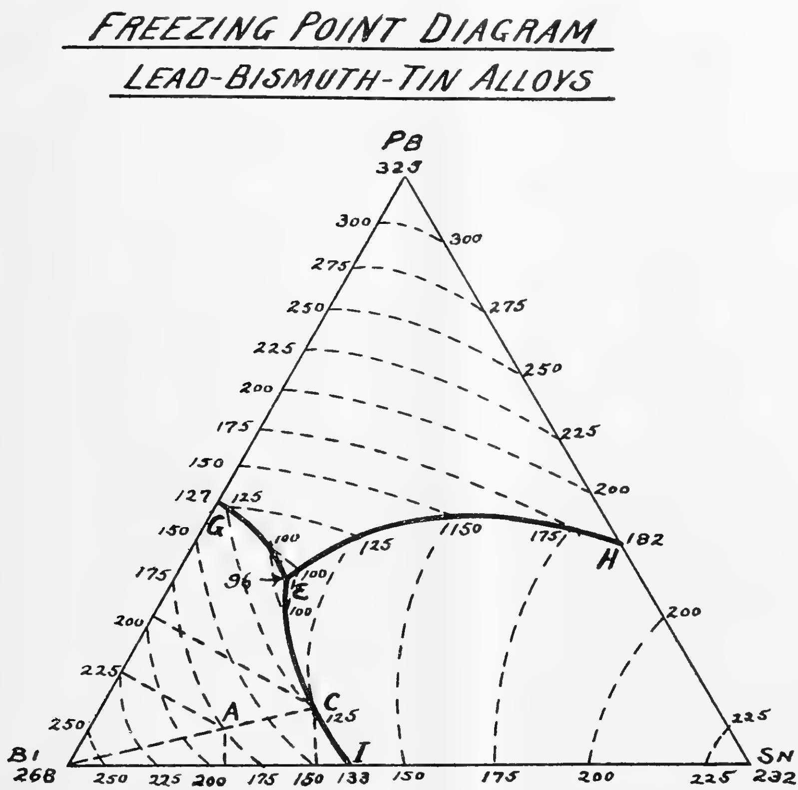

Fig. 8

$51\frac{1}{2}$ per cent. Bi, $15\frac{1}{2}$ per cent. Sn, and 33 per cent. Pb freezes at constant temperature.

This is about the limit of our capabilities in indicating the solidification conditions. For a greater number of components, or where other factors enter, the representation becomes a space-problem of four or more dimensions, which is really beyond our powers.

COMPARATIVE MICROGRAPHS

Figures 9, 10, and 11 show the striking similarity between the structure of rocks and alloys as revealed by the microscope. In each case the rock-section is on the right, beside its analogous alloy-structure on the left.

In the upper left-hand corner of Fig. 9 is the structure of a three-component mixture of 74 per cent. Bi, $5\frac{1}{2}$ per cent. Sn, and 21 per cent.

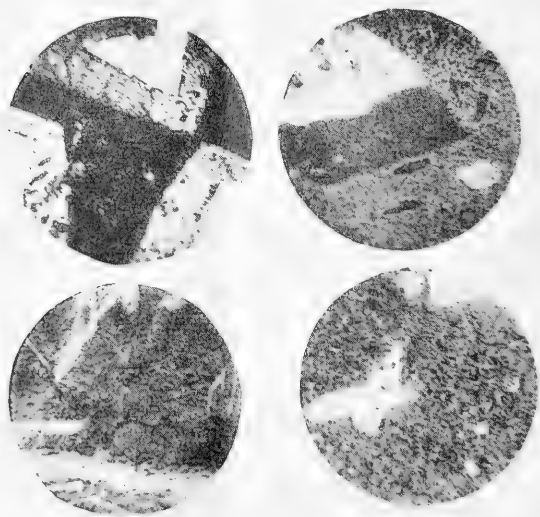

FIG. 9

Pb. The excess bismuth has separated out into the white masses; surrounding these is the binary eutectic of bismuth and tin, and finally, as the central black constituent, we note the ternary eutectic. A somewhat similar rock-texture is on the right, a rhyolite with the white quartz, the dark orthoclase, and the finer remaining ground mass.

Below on the right is a section of Augite porphyry, with the white plagioclase, adjoining this the gray augite, and inclosing all the fine texture of the ground mass of plagioclase and augite. It is very simi-

lar to the metal structure on the left, a steel with an excess cementite, and a eutectic pearlite, made up of this cementite and ferrite.

It is not the purpose of this article to discuss these sections in detail by trying to point out their methods of freezing; it is desired solely to show that two such classes of material as metals and rocks, widely different as they are ordinarily considered to be, in reality display the same peculiarities of texture.

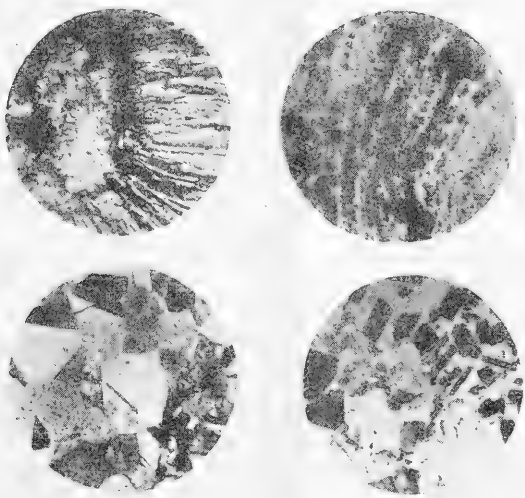

FIG. 10

APPLICATIONS TO IGNEOUS ROCKS

In endeavoring to point out the similarities in the solidification of certain alloys and magmas, one is limited to simple cases to which the theory of solubilities is easily applied. That the same considerations apply to the igneous rocks is indisputable; for it is not a question of drawing an analogy between the alloys and rock-masses. It is, rather, the application of broad general principles to specific problems; the application of general laws of equilibrium which must cover all possible cases of solution, even though as yet we may be unable to

apply the details of their working. The igneous rocks are, as a rule, very complex, and may contain many component minerals or elements; also there is an additional complication in that solidification takes place very often under pressure. Pressure is of great importance in the consideration of vapors, and so difference of pressure may introduce additional complexity through the effect on the gases. Again, equilibrium conditions may not always be reached; for example,

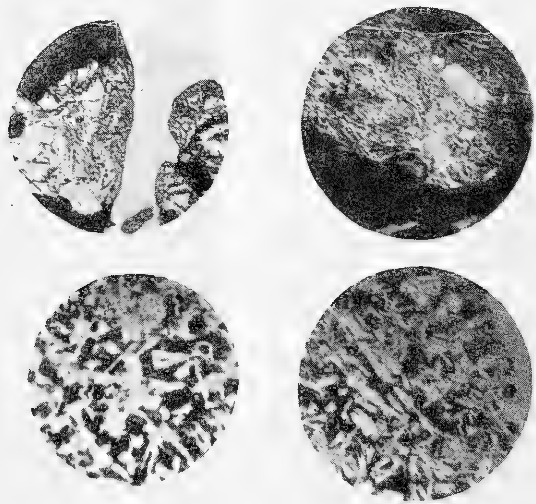

FIG. 11

with rapid cooling of the magma, supersaturation may have occurred with a change in the order of deposition of the minerals, or differences in the microscopic structure.

In the solidification of magmas, also, we have certain conditions which do not occur in the metallic alloys. We have discussed the composite nature of the eutectic structure. Among the metals, where the cooling is normal, this intimate mixture of the constituents is very common; with the slow cooling of the igneous rocks (especially when enhanced by their poor conductivity of heat) the long sojourn just below the temperature of transition may cause a segregation of

the eutectic constituents, and an elimination of the composite texture.

Furthermore, we do not make alloys in which the components are not perfectly miscible when molten, because in this case there will be separation by liquation and a defeat of the object sought by the mixture of the metals. But igneous-rock mixtures are not of man's choosing. Consequently there will very likely often be encountered the case of mixtures of imperfect miscibility, with a first separation of the components of saturation, and their final solidification according to the laws of freezing.

To clear up the intricacies of the problem, it is essential that extended research be conducted along the line of the few cases already worked out, beginning with the simpler conditions and extending the scope as circumstances warrant. With the electric furnace, desired minerals or rocks could be melted and could also be synthesized under any pressure; the pyrometer would give us the thermal reactions; finally with the microscope we could compare the structure of our artificial material with the natural rock in its original and remelted states. An investigation of this kind may reduce cases of seeming complexity to ones of comparative simplicity, by fixing a certain few of the components as of primary importance, and the rest of a secondary modifying nature. For example, while steel is a many-component alloy of Fe, C, Si, S, P, and Mn, we treat it as a two-constituent mixture of Fe and C as of greatest importance; the other elements have their influence mainly in their effect on the transition ranges of the carbon and iron.

At any rate, the thermal investigation has the great advantage of getting at the internal reactions, and can be backed up by our present methods with the microscope, and otherwise, which are suitable only for the end reactions.

In conclusion, it is well to bear in mind that the laws of equilibrium of solutions show that the melting-points of the constituents are of no service in predicting the order of their separation in the solidification of the magma. And is it going too far to predict that the study of the freezing-point diagrams of the conditions of this separation may result, as did Van't Hoff's application to the carnallite deposits at Strassburg, in economies in the recovery of the metals from their ores?

Reviews

Los temblores en Chile: su causa inmediata y el porqué de sus efectos. Por Miguel R. Machado, Jeologo del Museo Nacional, Miembro de la Comision del Temblor del 16 de Agosto de 1906. Santiago de Chile, 1908.

This paper on earthquakes in Chile is a separate of 28 pages taken from some publication not mentioned. It is of special interest just now as representing the views and conclusions of a Chilian geologist, who was a member of the commission appointed to study the Valparaiso earthquake of August 16, 1906, and who traveled over a large part of the region affected by that particular earthquake.

The author says that he failed to find any single center of disturbance, but he did find a multitude of areas of high intensity; he thinks it impossible to lay down isoseismal lines on a map. Passing over interesting local details, at pp. 54, 55 are given the following conclusions which are here translated that they may speak for themselves.

1. In Chile earthquakes are strongest in places located near certain classes of eruptive rocks that made their appearance in the Tertiary or about the close of the Secondary. These rocks are sometimes found lifting the beds formed during the Secondary period.

2. This rock has a granitoid appearance and a light gray color with greenish spots of amphibole. Sometimes it has a porphyroid appearance. In certain places it might be called syenite; in others granitic diorite; but it always contains amphibole and orthoclase feldspar in varying quantities; and this rock moreover is very modern. I think that in Chile this rock should be given the name of the earthquake rock or seismic rock. [Here follows a list of localities where this rock occurs.]

3. The earthquake rock is often found cut by gold-bearing shoots, dikes, and veins. For this reason the towns, settlements, and walls near places rich in gold, whether in the form of veins or gold washings, suffer more than those that do not have this precious metal. [Here follows a list of localities that have suffered.]

4. Buildings and walls on streets parallel with the direction of the earthquake rock have suffered very much more than those at right angles to it, where structures fall indifferently on either side of their foundations. . . . .

5. I calculate that the maximum destruction was produced in a zone of less than four kilometers on both sides of the ridge (cerro) in which the earthquake

rock occurs, and within which the better constructed buildings suffered, even when built upon a good subsoil. Outside of this zone the character of the subsoil, foundations, and building materials have but little influence.

6. Persons living on the earthquake or close to it often hear subterranean rumblings resembling that produced by a train passing through a big tunnel. . . . .

[7 consists of a description of the subterranean sounds.]

8. It is noted in my studies of each locality that destruction is caused always along certain lines more or less perpendicular to the sea, and consequently to the Andes ranges, and that they frequently extend to both of the transverse valleys. . . . . When seismic vibrations follow these lines the places along them receive vertical shocks and movable objects on the surface move in the direction of the vibrations, that is, toward the east.

In regard to the geologic relations of Chilean earthquakes the author further concludes (pp. 57, 58):

The strata or layers of rock laid down on the bottom of the sea during the Secondary and part of the Primary periods are now many thousands of meters above sea-level forming the present Andes. These enormous masses of detrital rocks began to be raised in the Tertiary period, pushed up largely by the rock we have called "seismic." This upward movement is not yet ended, for our coast is gradually rising at the rate of about one meter per century. [There follows a theory of an ancient submerged continent to the west of the present one.] The sinking of this ancient continent of the Pacific gave rise to the present American continent, and in order that these gradual and sudden uplifts should be brought about on the coast of Chile it is necessary that the bottom of the sea should be depressed. [At this place the author inserts the following footnote: "Sr. Montessus de Ballore, professor of seismology, in a lecture at the University of Chile announced as a new idea that the earthquake of August 16, 1906, had affected more violently the towns in front of the great heights of the Andes and consequently adjoining the greatest (ocean) depths. As this gentleman does not mention the source of this idea, we call his attention to this point which we had already set forth."] These elevations and depressions tend to produce a break or fault. In some places these faults appear in the littoral belt, but on the coast of Chile they are beneath the water; and for this reason the towns on the coast suffer more than those in the interior.

In Chile it happens that two earthquakes never occur in succession in the same place. I believe this is due to the fact that the continent of the Pacific (the submerged one) requires a greater pressure to lift the American continent. This it obtains in time, while the rivers of Chile are bringing down heavy materials derived from the Andes. Thus we have here a kind of balance in which one of the arms slowly furnishes the other with a weight sufficient to disturb the equilibrium.

J. C. BRANNER

Illinois Geological Survey. By H. Foster Bain, Director, and Others. Bulletin No. 8, 1907. 391 pp., 23 pls., maps. Springfield, 1908.

The report contains the following papers: "Steam Improvement and Land Reclamation in Illinois," "Petroleum Fields of Illinois," and "Mineral Industry of Illinois," by H. F. Bain; "Salem Limestone," by Stuart Weller; "Water Resources of the East St. Louis Region," by Isaiah Bowman; "Stratigraphy of Southwestern Illinois," by T. E. Savage; "Notes on Shoal Creek Limestone," by Jon. Udden; "Cement Materials near La Salle," by G. H. Cady; "Clay Industries," by E. F. Lines; "Experiments on Amorphous Silicas of Southern Illinois," by T. R. Ernest; "Artesian Wells in Peoria," by J. A. Udden; "Lead and Zinc District of Northwestern Illinois," by U. S. Grant and M. J. Perdue; " Concrete Materials Produced in the Chicago District," by E. F. Burchard; Extracts from *Educational Bulletins* by Messrs. Barrows, Trowbridge, Jones, Atwood, and Goldthwaite; also articles on "Coal" by Messrs. Parr, Wheeler, Hamilton, Bain, Francis, Bement, DeWolf, Udden, and White.

The petroleum industry showed a marked advance. In 1907 the state produced 24,540,938 barrels of petroleum or about one-seventh of the total production of the United States. The oil horizons are mainly in the Carboniferous rocks. C. J. H.

Report of the Vermont State Geologist. By G. H. Perkins. On the Mineral Industries and Geology of Certain Areas of Vermont, 1907–8. 302 pp., 59 pls. Concord, N. H., 1908.

This report is the sixth of the present series and contains the following papers: "Mineral Resources," "Fossil Cetacea of the Pleistocene," "Geology of Franklin and Chittenden Counties," by G. H. Perkins; "Granites of Vermont," by T. N. Dale; "Shore Lines in Northwestern Vermont," by H. E. Merwin; "Geology of Hanover Quadrangle," by C. H. Hitchcock; "Geology of the Town of Swanton," by G. E. Edson; "Stellae and Rhabdoliths," by H. M. Seely; and "Geology of Newport, Troy, and Coventry," by C. H. Richardson. The production of the building stones, granite, marble, and slate, has steadily increased, amounting to the total value of $10,000,000 yearly. C. J. H.

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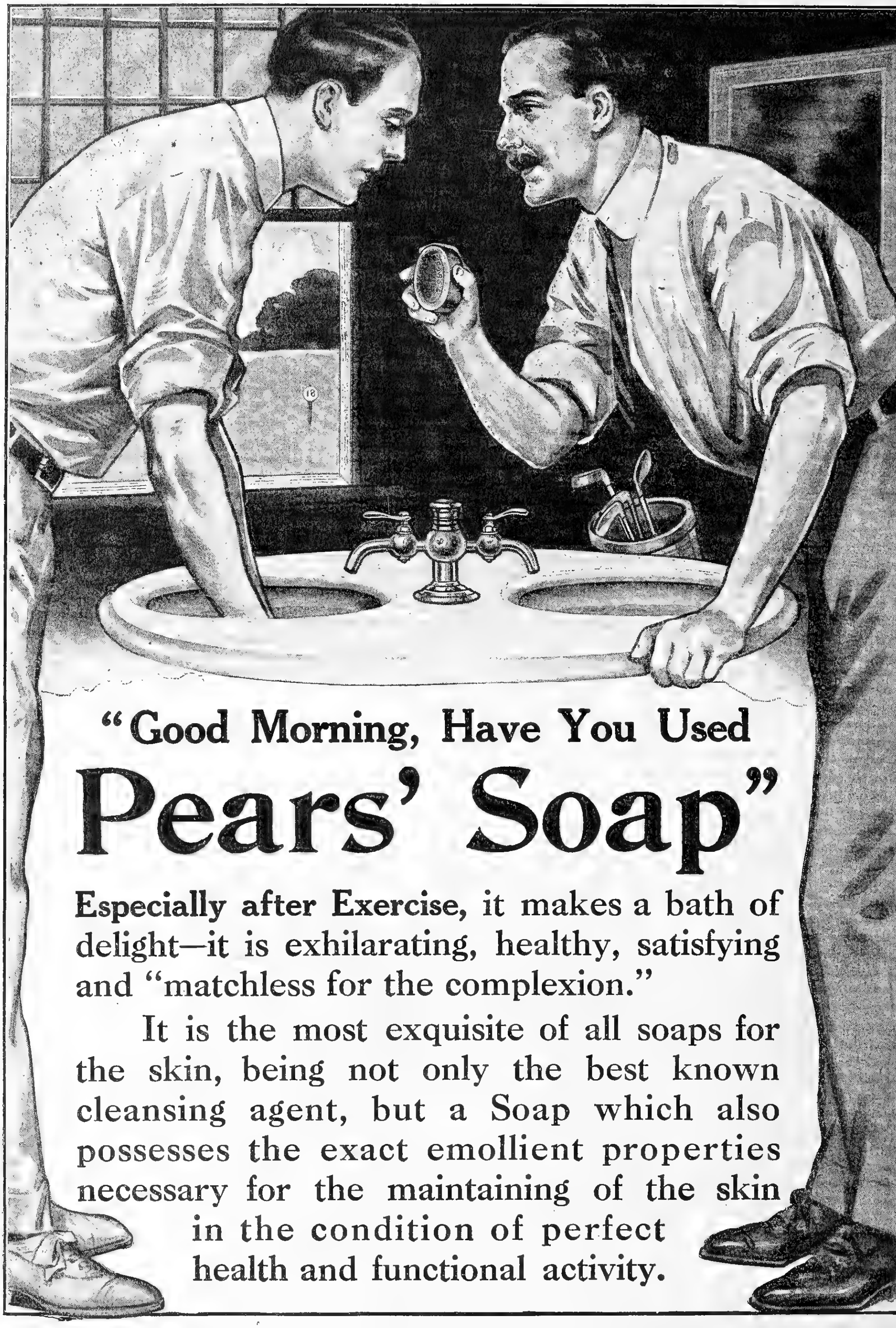


OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1909

PHYSICAL GEOGRAPHY OF THE PLEISTOCENE WITH SPECIAL REFERENCE TO PLEISTOCENE CONDITIONS

ROLLIN D. SALISBURY
The University of Chicago

XIV[1]

The character of the changes which marked the transition from the Tertiary to the Quaternary were somewhat unusual, though not unique as they were once believed to be. Great as these changes were, they were probably not equal in magnitude or importance to the changes which marked the transition from one great era of the earth's history to another. The significant changes at the close of the Tertiary are those which had to do (1) with the height and extent of the land and, perhaps as a result of these changes, (2) with profound alterations of climate, bringing on (3) glaciation on an extensive scale, and causing (4) migrations and mutations of life.

I. THE PHYSIOGRAPHIC CHANGES

The changes in altitude which affected the North American continent late in the Tertiary have not, in most places, been worked out in such detail as to lead to numerical results in which implicit confidence can be placed; but the general tenor of the evidence is harmonious, and the main conclusions are probably correct in their general terms. They may be summarized briefly as follows:

[1] Professor H. F. Osborn's article on "Environment and Relations of the Tertiary Mammalia," No. XIII of this series, will appear in a later number of the *Journal*.

1. In the eastern part of the continent, the land is generally thought to have stood higher than before by some few hundred feet. If the more extreme views of a few of the geologists who have studied this question are accepted, the excess of elevation over the present was a few thousand feet.

2. In the larger part of the Mississippi basin, the gain in altitude was considerable, though still on a relatively moderate scale. In the eastern and central parts of the basin it is probably to be measured by a few hundreds of feet, rather than by figures of a larger denomination. There is some reason for thinking that the important topographic features of the central Mississippi basin are chiefly of late Tertiary and post-Tertiary origin, developed from a late Tertiary peneplain now represented by the summits of the higher hills and uplands of the region, a few hundred feet above the general level in which the present valleys are sunk. It is true that these summits have sometimes been interpreted as remnants of a Cretaceous peneplain; but this conclusion is not firmly established, and the alternative suggested above is entitled to consideration.

3. In the west, the relative uplift in the closing stages of the Tertiary and early Pleistocene was greater. The estimates of the late Tertiary and post-Tertiary uplift here at one point and another range from several hundred feet to several thousand. The figures are most definite and perhaps most satisfactory near the Pacific coast. In southern California, the uplift at this time has been estimated at 1,500 feet; in northern California, 1,500 to 2,000 feet; and in the Sierras at 3,000 to 6,000 feet. In Oregon, Pleistocene marine fossils are found up to elevations of 1,500 feet, while in and about the Cascade Mountains of Washington, an elevation of several thousand feet, maximum, seems to be well established.

In British Columbia, the relative upwarp of the corresponding time has been thought to reach an amount comparable to that of the Cascade Range, while, farther north, most of the estimates point to less extensive changes. The old peneplain which is now at an elevation of 6,000 to 9,000 feet in Washington and British Columbia, is thought to descend to 4,000 or 5,000 feet far to the north. While the age of the deformation which brought the former peneplain of these northern lands to its present position has not been fixed with

precision, the best opinion seems to place it, or at least its initiation, in the late Pliocene and early Pleistocene.

Students of the western interior have reached no general agreement as to the amount of late Tertiary and Quaternary change of level, but there is general agreement that the land of that region was notably higher at the close of the Tertiary, and later, than it had been before. The increase in the height of the land amounted, perhaps, to a few thousand feet in some places, but was probably far from uniform.

4. In the West Indies and Central America, the interpretation of facts and supposed facts seems to be more or less uncertain. Spencer would make the amount of change of level in the West Indies within this general period very great, even 8,000 to 11,000 feet higher than now. Hill would have some portions of Cuba at least 2,000 feet higher than now at or since the close of the Tertiary, and the Barbadoes 1,100 feet higher at about the same time, while Hershey thinks the Isthmus of Panama has been bowed up 1,000 feet or so since the beginning of the Pleistocene.

If even the more moderate of these figures are correct, it appears that the average relative increase in the altitude of the continent must have amounted to several hundred feet at least. This amount of elevation must have been adequate (1) to increase erosion by streams greatly, this increase resulting both from (*a*) increase in precipitation, and (*b*) increase in gradient of the streams; (2) to lower in some slight measure at least the average temperature of the land, and to increase its range; and (3) to reduce the amount of vegetation on the average, both because of (*a*) the unfavorable change in temperature and (*b*) the more rapid erosion.

Outside of North America, similar changes seem to have been in progress. Thus in South America, such determinations as are at hand point to an elevation approaching 3,000 feet at a maximum on the west coast of South America, since the late Tertiary. Changes of similar import, and perhaps of comparable extent, are indicated by the facts reported from other continents, though for all but Europe, the facts are meager. In Europe, changes of level at the close of the Tertiary were not everywhere great, but about the borders of the Alps, the increase of elevation is estimated by Penck and Brückner to have been 300 to 500 meters.

It should be noted that the deformations of this time were more important in affecting the height of the land than in affecting its area. Yet from the evidence of existing floras and faunas, it seems probable that the up-swelling of the contiguous parts of America and Asia were sufficient to connect them by way of the Aleutian Islands. Shaler and Spencer have urged reasons for thinking that Florida and Cuba were connected in the late Pliocene or early Pleistocene, but this conclusion cannot be said to be established. In Europe, within the same general period of time, England has probably been joined to the continent, and southern Europe to Africa. Submerged valleys on the northwestern coast of Europe, if interpreted in the usual way, indicate elevations several hundred to a few thousand feet greater than those of the present, enough, if some of the estimates are correct, to have connected Europe with Greenland and North America. If such a connection existed, it must have entailed changes in oceanic circulation sufficient to have affected the climates of high latitudes in an important way.

The very considerable changes at the beginning of the Quaternary were followed by a great succession of changes as the period progressed. Some of them reinforced the changes just sketched, and some of them were of the opposite phase. Oscillations of level during the Quaternary have been more carefully worked out along the coast of northern Europe than in America. Unexpectedly enough, evidence seems to point to greater depression during the glacial epochs than during the interglacial. The amount of the determined oscillations of level during the Quaternary range from a few feet to a few hundred feet.

II. EFFECTS OF PHYSIOGRAPHIC CHANGES ON CLIMATE

In many parts of the earth, as in the interior and eastern part of North America, in Europe, and elsewhere, the increase of elevation at the end of the Tertiary was probably not sufficient to be of great importance climatically, in a direct way. In other regions, as in the western part of North America, on the other hand, the gain in height was probably sufficient to produce considerable effects directly.

In an indirect way, the effect of the increase of average altitude of land on climate may have been much more considerable. Erosion

was stimulated by the increase of altitude and by the decrease of vegetation due to the causes already mentioned. The increased rate of erosion led to the removal of the residual earths and alluvium which may well have accumulated on the surface to very considerable thickness, and the removal of these materials from the surface exposed the underlying rock to decay.

If changes in the constitution of the atmosphere are to be regarded as the cause, or as even one cause of climatic change, the increase of erosion at the close of the Tertiary would have led to an increased consumption of carbon dioxide, and so may have been responsible for the initial step in the series of changes which brought on the glacial climate. Though it is, perhaps, too early to affirm that the increased altitude of the land at this time was the basal cause which led to the cold climate which followed, this is a hypothesis toward which students of glacial geology are looking with much hope.

If the increased height of the land led to increased erosion, and so to increased consumption of carbon dioxide, the reduction of the amount of this gas in the atmosphere would have lowered the temperature everywhere. The resulting decrease in the temperature of the sea would have led to an increased solution of carbon dioxide from the atmosphere, thus depleting the atmospheric supply still further, and this, in turn, reacted upon the temperature and became a cause of its further reduction. This cause, therefore, once in operation, must have continued with increased effectiveness until the decay of rock was checked by decrease of altitude or temperature, or by the accumulation of ice-sheets which protected the rock beneath from ready carbonation.

III. THE DIRECT IMPORTANCE OF THE ICE-SHEETS THEMSELVES

Irrespective of the cause of the glacial climate, the covering of six million or more square miles of land in the northern hemisphere with ice hundreds and thousands of feet in thickness was in itself an extraordinary event which might well serve as an important landmark in geologic history. The ice-sheets, and especially the remarkable successions of ice-sheets, might appropriately be emphasized as proof of one of the most remarkable climatic incidents in the history of the earth, so far as now known. But apart from its great climatic signifi-

cance, each ice-sheet meant the relatively rapid superposition upon the northern continents, over the great areas indicated, of a new layer of rock, the ice, which for tracts of millions of square miles must have had a thickness exceeding a thousand feet, and perhaps a thickness of several thousand feet. The aggregate volume of this new rock, superposed on the northern parts of the northern continents, was such that it could only have been measured in terms of millions of cubic miles. The withdrawal of its substance from the sea effected a corresponding lowering of its surface, an appropriate extension of land, and an increase in its height above the sea.

Though this great body of rock new-laid upon the lands was temporary in its character, primarily because of the low temperature at which its substance assumed the liquid form, it was of great importance, from a geologic point of view, in more ways than one.

1. In the first place, the loading of millions of square miles of land with such a weight must have had an appreciable effect upon crustal movements, if the doctrine of isostasy has validity, and its disappearance, under climatic conditions which developed later, must have produced movements of the same class, but of opposite phase.

2. Again, the development of the ice-sheets put a virtual stop to the processes which had been in operation over six millions of square miles of the land, and set other processes into operation in the same places. Thus the normal phases of river work were suspended, most rivers within the ice-covered area ceasing to flow altogether. The usual phases of rock weathering and decay were practically stopped over the same areas, areas which, in the aggregate, were a very considerable fraction of the surface of the land. On the other hand, a new process of erosion was substituted for the old—erosion not restricted chiefly to the removal of decayed rock.

3. The changes in erosion were hardly greater than those in sedimentation, for instead of the assortment and separation of decayed material into its several physical classes before deposition, fine sediments and coarse, largely of undecayed material, were left promiscuously commingled. Thus on a large scale and over enormous areas deposits were made which were unlike those of comparable extent at any other stage of the earth's history, unless at times when climates were similar.

4. It should be noted further that the changes in the processes of erosion and sedimentation—changes in kind as well as in rate—were not limited to the areas actually covered by the ice, or even to the areas affected by drainage from it, or by icebergs which floated out beyond its edge. Modifications of erosion and sedimentation were felt in all areas affected, directly or indirectly, by the change of climate.

The great ice-sheets, with the recurrent disturbance which they probably occasioned in the crust of the earth and the lesser changes in the surface of the ocean; with their recurrent inhibition of the usual processes of erosion and sedimentation over great areas; with their recurrent modification of these processes over other great areas beyond the ice-sheets themselves; and with their recurrent inauguration on a large scale of processes of erosion and sedimentation which were unusual, might, without consideration of further changes of an indirect character, furnish adequate bases for important time divisions. Especially is this the case since the influence of the ice-sheets must have been felt in a physical way, throughout most if not all the earth.

IV. CHANGES IN LIFE

The great changes in the physical processes, which this on-coming of the ice-sheets brought into operation, effected corresponding changes in life, and in the processes which depend on life. In the first place, the total amount of land life must have been greatly reduced. If account be taken of mountain glaciation in both hemispheres as well as of the ice-sheets, it is probably within the limits of truth to say that conditions became so far inhospitable as nearly to eliminate land life from about one-seventh of the land of the globe, and to have rendered conditions relatively inhospitable over a still larger area. The effect upon the life of the sea is less easily stated, but it also must have been great, for the average reduction of the temperature of the sea must have been considerable.

The crowding of land life off 8,000,000 square miles, more or less, must have tended to concentrate it upon the land which still remained hospitable, and to decimate or exterminate those forms which could not migrate readily. Migration must have been forced upon the sea life as well as upon that of the land, and the shifting of the zones of both must have resulted in a shifting of the sites of organic deposi-

tion, perhaps especially of the sites where limestone was made. At the same time, the rate at which it was formed, the whole earth considered, was probably much reduced.

It would seem, from the series of physical changes sketched, that very profound changes in life should have followed, but it must be confessed that, in spite of the conditions which it would seem must have been favorable for great destruction of life, and for imposing great modifications upon that which survived, statistical evidences of the changes which followed are less impressive than would have been expected. The data at hand do point to extensive migrations, but not to the exterminations and profound modifications which might have been anticipated. It seems impossible to think that the changes of climate which drove musk oxen to Kentucky and Virginia, and Arctic plants and reindeer to the lowlands of central Europe and to the Mediterranean, were without very profound biologic significance, unless the life of the earth had reached a condition of far greater stability than that of earlier times, when lesser physical changes seem to have produced greater biological changes.

One of the features of the late Tertiary land life, and especially of the floras, seems to have been the great extent to which types were mingled. This mingling of tropical or sub-tropical forms with temperate and boreal ones seems to have begun as early as the middle of the period. The oscillations of climate which marked the Pleistocene seem to have had a sifting influence upon the migratory forms, and to have forced them to special adaptations and habitats as the period progressed. This is suggested, for example, by the floras of America and Eurasia. Gray pointed out long ago that the forest flora of the eastern part of North America is more like that of Japan than like that of the western part of our own continent. In Europe, the north-south and south-north migration of the floras as ice-sheets advanced and receded was interfered with by the east-west mountain ranges and by the seas bordering Europe on the south. In eastern Asia and America, on the other hand, the back-and-forth migration of the floras was facilitated by the greater continuity of land between high and low latitudes, and in America at least, by the absence of east-west mountain ranges. In the western part of the United States, the irregular topography made repeated latitudinal migrations of the

floras more difficult than in the eastern part, though perhaps less difficult than in Europe. In eastern Asia and in eastern America, where migration was relatively easy, the forest flora is much larger than in Europe or western North America. Thus Atlantic America and Pacific Asia have each 66 genera of forest trees, while Pacific America and Europe have but 31 and 33 genera respectively, and the number of species is approximately in keeping with the number of genera.

Vulcanism has been regarded as a factor which decreased the flora in the western part of North America as compared with the eastern; but since the floras were much the same throughout the Tertiary in all northern lands, and since the climax of Cenozoic vulcanism came as early as the Miocene, the importance of this factor in impoverishing the Pleistocene life of the western part of the United States may be questioned. Furthermore, it has little or no application to Europe, where the flora was equally reduced.

The to-and-fro movements of the land faunas and floras must have introduced an elaborate series of superpositions, giving an elaborate, orderly, and unusual succession. The record of this succession has not been worked out in its completeness, and unfortunately there is little chance that it will be worked out in its fulness unless by the most persistent care. In the regions which were glaciated repeatedly, the advance of each ice-sheet destroyed, in most places, the record of the successive floras and faunas which had lived since the preceding retreat, so that, within the area glaciated, the succession of successions is hardly likely to be found in its entirety in any one place, and perhaps not in all places. Outside the area which was glaciated, especially near the borders of the regions occupied by the successive ice-sheets, there is better chance that a complete record of the biological changes may have been preserved. The peat bogs of such regions might be expected to give complete records if they had endured continuously since the time of the first glaciation; but peat bogs are themselves temporary, and it is perhaps too much to expect that complete record of the migrations of life during the successive epochs of the glacial period will ever be found at any one place.

The records, however, of the post-glacial peat bogs are such as to give some indication of the results which would probably be found

if all the migrations could be ascertained. Thus in Scandinavia and Denmark, we have a succession of post-glacial floras, the first corresponding in a general way to the present vegetation of the tundra, the second a forest vegetation dominated by the birch and poplar, the third a forest vegetation dominated by pines, the fourth, one dominated by the oak, etc., the fifth a flora similar to that of the Black Forest Mountains, indicating a temperature warmer than that of today for the same region, and finally, a southward retreat of the last flora to its present latitude. The first five members of the succession seem to correspond with the half of a normal interglacial series. If this interpretation is correct, this series of five floras would be nearly doubled with the on-coming of another glacial epoch, and this doubled series must have been repeated, substantially, several times in the course of the long succession of glacial epochs. Fragments of interglacial records have been found both in America and Europe. In a few cases they are full enough to encourage the hope that when their number is duly increased, they may be pieced together into consistent wholes. It is too much to expect that they will ever be as complete as the record of post-glacial life.

It is not now apparent just how far biologic or paleontologic data of the Pleistocene, except from their record of climatic changes, are to be significant in correlation. Aside from the mammals, changes of species have been insignificant. Even among mammals, it is not clear that the dying-out of species in one locality was contemporaneous with the disappearance of the same species in other localities. A stratigraphic basis for this interpretation would be needed before it could be accepted. So far as all other forms of life are concerned, the paleontologic record of one interglacial epoch must have been essentially identical with that of another, if the intervals were equally long and mild.

Perhaps more help in correlation may be looked for in another direction. Intercontinental migrations, it would seem, must have been virtually restricted to interglacial epochs. The times when species first appeared in a given region may therefore prove to be much more significant in correlation than the times when species died out.

Something perhaps may be hoped for in the careful study of the

records of oscillations of level, during the period; but it seems clear that different parts of the same continent have suffered minor or even considerable deformations, independently of others. If it were established that opposite sides of an ocean basin were less independent in this respect—a doctrine for which much might be said—the movements on opposite sides of an ocean basin might be a hopeful line of research; but it cannot, at the present time, be said to have led to important conclusions.

It would appear that only through a combination of stratigraphic, climatic, paleontologic, and orogenic studies, carried out in greater detail than they have yet been, can important results in the correlation of Quaternary formations be reached, between widely separated areas.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

QUATERNARY NORTH AMERICA

North America during the Quaternary presents very unusual features. The land area is large. The margin of the continental plateau is now somewhat submerged, but probably has not been so throughout the period. Marine embayments are not extensive, except Hudson Bay, which is a fair example of the smaller epicontinental seas that have spread over various parts of the continent in the past. Mountain systems that are great in extent and height have grown from the places of the early Tertiary ranges of the Cordillera, which had been deeply eroded before the Pliocene. The Appalachian Mountains, which began to rise above the plains of eastern America possibly as early as the Eocene and which toward the close of the Miocene had ceased to grow at something less than half their present greatest height, have been raised to their existing altitudes during the Quaternary.

These mountain features of North America are paralleled or exceeded in other continents and the period is thus characterized as one during which the forces that raise mountains have been decidedly active.

In late Tertiary time great differences of climate developed. The equatorial, temperate, and polar zones became much more unlike than they ever had been, according to the geologic record. The Quaternary is distinguished by the development, the advances, and retreats of several ice sheets, whose combined areas are shown on the map. The expanse of ice was at no one time so great, but the entire area shown as ice was covered at one time or another, and some parts of it several times successively, by continental glaciers.

[1] Published by permission of the Director of the U. S. Geological Survey.


QUATERNARY
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS
LANDS
ICE
MARINE CURRENTS POLAR
EQUATORIAL
600 miles
120°
110°
100°
90°
80°
70°

The developments of topography and climate, including polar refrigeration and corresponding modifications of oceanic conditions, have greatly changed the environment of plants and animals, and have resulted in special phenomena of competition and adaptation, through which existing forms have been evolved.

ORIGINATION OF SELF-GENERATING MATTER AND THE INFLUENCE OF ARIDITY UPON ITS EVOLUTIONARY DEVELOPMENT

DR. D. T. MACDOUGAL

XV

Any attempt at an interpretation of a desert landscape, with its diversity of forms, isolation of individuals, and scarcity of organic matter in the soil, leads inevitably to a consideration of the theoretical conditions which would be necessary in the origination of the physical basis of life, its development into organisms known to us in the living and fossil state, and also of the possibilities of the occurrence of a re-generation at the present time.

From almost every excursion which the biologist has made into this inviting field of speculation on which he has called to his aid various extreme or unusual intensities of the factors to be taken into account, he has been ruthlessly recalled by the geological historian with the reminder that the general composition of the atmosphere, its pressure, the temperatures, and other conditions prevalent on the earth's surface were uniform and continuous with those now encountered and not widely different, in their total departure, in any stage of terrestrial development in which life might have originated.

Now we are not able to discover that living or self-generating matter is actually being formed anew on the earth's surface at the present time, and in the absence of positive evidence we are compelled to say that all life now in existence must have descended from forms which had their ultimate origin in other times and under other conditions than those now prevalent.

A consideration of the phyletic aspects of fossil and living forms of plants yields but little, which might serve as an indication of the conditions under which the earlier forms developed. Even the earliest remains include such advanced types as the ferns and cycads. The amount of progress represented by the derivation of the gameto-petalous seed-plants from these, in comparison with the preceding

evolution, is quite insignificant, while even the simpler forms of animals and plants are to be considered as types widely divergent from primitive self-generating matter, being removed from it by the slow but sure advances of untold millions of years of development.

It is, therefore, as if we had observed the events and objects of yesterday and were called upon to read the history of the past century. In the search for supporting ideas upon which to base speculation, two conceptions serve as encouragement for a renewed attack upon this fascinating problem. One is embraced by Chamberlin's planetesimal theory of the growth of the earth and the attendant modification of surface conditions, which necessarily showed a complex widely different from the present, and the other is one, growing in favor with physiologists, to the effect that the essential activities of living matter rest upon catalysis, and enzymatic processes, with the characteristic reaction velocities directly affected by internal and external limiting factors. The protamic nucleus may be taken to represent the first form in which self-generating matter might be said to have the characters of protoplasm, but previously to its synthesis there must have occurred an increasingly complex series of carbon compounds, with hydrogen, oxygen, nitrogen, sulphur, and phosphorus, while iron, calcium, magnesium, and potassium are also involved in its activities at the present time. That these main constituents were present in the atmosphere at partial pressures of varying intensity, and that unstable carbides, nitrates, phosphides, and sulphides brought by infalling planetesimals were passing into more stable unions with the formation of hydrocarbons, ammonia, hydrogen phosphide, etc., is suggested by Chamberlin, and the possible interactions and combinations might result in the synthesis of very complex substances, well up toward the simpler forms of living matter. The hypothesis formulated by him also assumes that the surface of the earth was unworn piled talus, but little of which had gone into solution. The development of the hydrosphere moistening this layer, and forming pools and small bodies of water all exposed to the light of the sun, together with the variations in temperature, partly due to the heat of impact of infalling bodies, the influence of magnetic fields induced by bodies circulating about the earth would determine the paths of ions and electrons traversing

them, while in addition other states of ionization, due to radioactivity, would all be possible factors contributory to a synthesis that might form a beginning of the physical basis of life. Any resulting thermo-catalyzer would be a possible agent for self-organization, and in the development of an organic type its characteristic activities would consist in the degradation, or reduction of the potential energy of the medium or substratum and the oxidation of the acquired substances. Living matter is in fact a thermal engine in which the oxidation is, comparatively, exceedingly slow.

FIG. 1.—Mud-volcanoes of Lower California, in and around which unusual opportunities for chemical combination are offered by the conditions of temperature and pressure.

No process observable by available physiological methods suggests the origination of living matter, yet it seems quite probable that combinations similar, analogous, or even identical with the earliest forms of living matter might be produced in the laboratory, in inclosed spaces or under special conditions. Doubtless compounds of much greater intricacy have been made, but while we might make such substances, yet it would be extremely difficult for us to furnish the supply of material and the continuance of conditions which would permit this matter to exercise its initial functions of self-generation to any appreciable extent. The starting of a strain of

living matter which might perpetuate itself and evolve into differentiated forms will long remain one of the most difficult feats which confronts the experimenter. The tests and criticisms which have been applied to the results of the few essays that have been made for the production of bodies which would be self-maintenant in a suitable medium, have been, for the most part, misdirected. Thus in the consideration of the hitherto unsuccessful efforts to produce bodies simulating some of the properties of self-generating matter, tests for the physical and chemical properties of protoplasm as well as for phenomena of the cell have been applied, regardless of the fact that the cell probably stands removed by a million years of evolution from the simple living material which first took shape, and represents, in fact, simply a successful form of organism and by no means the only possible morphological organization.

Such misuse of criteria has doubtless operated to curb research and discourage experimentation, and while it may have seemed soundly conservative for Kelvin to say:

> But let not youthful minds be dazzled by the imaginings of the daily newspapers that because Berthelot and others have thus made foodstuffs they can make living things, or that there is any prospect of a process being found in any laboratory for making a living thing. . . . . There is an absolute distinction between crystals and cells. Nothing approaching to the cell of a living creature has ever yet been made,[1]

yet the actual accomplishment of self-generating matter is, as suggested above, a theoretical possibility in the laboratory. The provision of a proper nutritive environment would present greater difficulties than the construction of a thermo-catalyzer capable of sustaining itself in a proper medium.

After growth and decay, the next most important property of living matter is that of irritability, of impressibility, and of accommodation to environment. The basic substance of protoplasm endured because of a capacity for withstanding the current range of temperature and insolation, and this endurance was made possible by fairly automatic adjustments, one of the simplest of which is encountered in recognizable form in living plants today in the decrease of water content, following lower temperatures acting upon proto-

[1] *Nature*, XXXI, 13, 1904.

plasm. Few adjustments are so simple, and, of course, more complicated ones became possible as atomic group after atomic group was added to the constituency of living matter.

Along with these acquisitions the feature of the rhythmic action which has become so characteristic and important for the living growth is to be considered, and this with contractility is dependent upon surface tension, viscosity, etc.

So far the properties suggested are those common to all living forms, but there must have ensued many differentiations of living matter, of which we have two survivals in plants and in animals. It seems probable that the first specialization resulted from the formation of substances in some of the living masses which converted radiations of certain wave-lengths into heat and other forms of energy active in promoting the reduction processes. A fortuitous movement toward such specialization may indeed have been the factor that made for survival in an environment of decreasingly available supply of chemical energy. The highest development of this power of absorption of light rays is to be assigned to chlorophyll, but preceding the formation of this very intricate and unstable substance there may have occurred a series of other compounds acting as heat-absorbent screens, of which the reddish and bluish pigments of the lower algae are surviving examples. Many disintegration products constituting the reds and blues of plant tissues sustain physical relations of a similar character to sunlight.

It is not possible to formulate any rational conception of living matter without including its environmental relations. These become of the utmost importance at the moment of formation of self-generating matter, and it may be assumed with perfect safety that of all the possible synthetic processes only those which ensued in the presence of a medium which furnished substances suitable for building material could survive. Furthermore, when the accumulation of this material and its specialization is considered it is apparent that successful origination occurred only on solid or semi-solid substrata rather than in undifferentiated solutions in open waters. Still an abundance of this liquid would be of great importance to the colloidal masses which we may think of as the earliest living things, and, as will be shown presently, water has continued to be the most important of all of

the constituents of development especially with regard to the vegetal organism. The first method of multiplication of individuals or colloidal masses undoubtedly consisted of simple fragmentation resulting from the accumulation of a mass too great to be held together by surface tension, and the separation of these masses must have been accomplished, or made possible by flotation which continues to be one of the most efficient agencies in the dissemination of plants, a fact specially emphasized by the results of our studies upon the revegetation of the Salton Basin.

An early specialization of structure probably rested upon the reduction of portions of the self-renewing colloidal masses from the suspended condition of a sol to the condition of a gel, and doubtless the limiting membranes of protoplasmic masses depend upon this process. Likewise some form of centrum resulted from congelation processes by activities of a nature elementary to the relations of the nucleus and cytoplasm in the modern cell.

Wherever portions of the colloidal mass came into contact with solid substances gelation or aggregation ensued, and the masses of material thus differentiated would give form and stability in place, representing the earliest form of anchorage organ. In this as well as in other features of the plant, evolutionary development was slow so long as the monotonous conditions of an aquatic habitat were to be met. Very simple processes or extrusions from a cell or coenocyte of this general nature are still to be encountered among certain algae.

As soon, however, as it was left stranded by the disappearance of the shallow waters in which it may have lived, or was lifted above the water level by any means, the diversified conditions encountered by the organism, including desiccation, exercised a differentiating effect on the root-organ scarcely less marked than those which may be ascribed to the same agency in the shoot. The necessity for anchorage was no less, but now the nutritive substances no longer bathed the entire body but were present only in hygroscopic solutions on the soil particles with a vertical distribution not uniform, and with much horizontal irregularity. Survival depended upon the formation of specialized tracts for absorption, and conduits for the transport of solutions from the organ of fixation to other parts of the living mass. It is to be noted, however, that the modern root arose anew from the

vegetative axis, and is therefore not directly derived from the primitive anchorage organs described.

The present occasion does not warrant a discussion of the evolutionary development of the vegetal organism from the colloidal mass to the gametophyte, now represented by the prothallium of ferns and their allies. Neither is it necessary to recall details of plant anatomy further than to point out that the earlier forms of plants, co-ordinately with the monotonous conditions offered by their acquatic habitats, showed no differentiation of tissues comparable with that of the axis of the modern seed-plant, and that their flattened bodies were for the most part closely appressed or adherent to the substrata. The development of the sexual type of reproduction in such forms had been followed by a habit of formation of the sexual organs separately, perhaps some distance apart on the upper or lower surfaces of the body. In the functionation of such organs the two kinds of protoplasts representing the sexual elements would be set free at the surface of the body and accomplish union while swimming freely, or in higher stages of development, the one representing the egg-cell would remain in place, while the fertilizing protoplast, or spermatozoon would find its way to it. In either case free water was absolutely necessary for reproduction. The body of the plant might be partially or completely immersed, or it might have only a thin film coating the surface, through which the sexual elements must move, but in either case the plant could not survive away from the margins of streams, seas, and lakes, or up out of the moist lowlands, or beyond the borders of rainy regions.

The thallose forms carrying on sexual reproduction do not appear to have been capable of the morphological development which might have gained them independence from the water, and this freedom was gained only after a secondary, asexual generation came into existence.

In the general movement which finally resulted in a land flora, the fertilized egg held in the body of the thallus would germinate in place, developing into a vegetative structure (the sporophyte) unlike the thallus which bore the egg. Then cells were cut off, or separated from the body of this alternate generation, known as the sporophyte, which had the power of developing into thalli like the

original. Now the germination and growth of these asexually produced spores could proceed in the absence of free water, and in ordinary soil in which all of the water present was represented by the hygroscopic layer coating the minute particles of which it is composed.

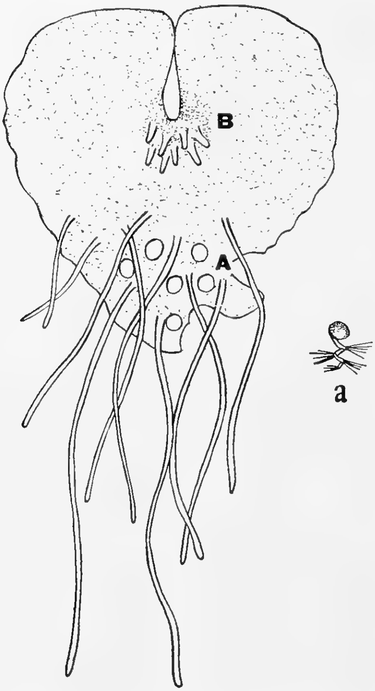


FIG. 2.—The gametophyte, or sexual generation of a fern. Reproduction is accomplished by the movement of a sperm (*a*) from the antheridium *A* to the archegonium *B* where it fuses with the egg, accomplishing fertilization. The sperm swims through a thin film of water which may be present. The absence of the film by aridity is unfavorable to the reproduction and continuation of this type of vegetation. The germination of the egg produces the sporophyte or fern plant ordinarily known (see Fig. 3).

Even with this development, however, plants could not get very far from the water, since this element in a free state was still necessary for the activities of the gametophyte, or sexual generation. The sporophyte, however, continued to increase in size and to wax in importance in the life-cycle of the species, until finally its body was much larger than that of the gametophyte. This feature is well illustrated by the tree ferns in which the sporophyte is a massive plant while the prothallium, or sexual generation, is a small thallose structure only a few millimeters across.

Eventually, however, the spores formed by the sporophyte, capable of living on dry land, were germinated in place, giving rise to sexual individuals, which were also held and nursed in the tissues of the sporophyte. Then in completion of the movement, accessory structures, including the pollen-tube, were formed, by which the sexual reproductive elements might be brought together independently of external conditions. By these steps the seed-plant originated and vegetation became truly and wholly able to occupy the land—a most

momentous change, and one of great importance in connection with the general subject under consideration.

Temperatures alone have been unduly drawn upon in the interpretation of distributional features of ancient and existing floras, a fact made more plainly apparent by recent observations at the Desert Laboratory, in which it has been found that several species range over a vertical mile. Such species endure cold of $-35°$ C. and have a growing season of less than a hundred days in the more boreal or alpine portion of their ranges, while in the southern or lower localities inhabited by them, temperatures of 48° C. may be encountered; the growing season extending over 300 days; the thermometer going below the freezing-point not more than 12 hours during the entire year.

It is with no surprise, therefore, that it is learned that there is no single feature in the structure and functionation of plants that with perfect assurance may be connected with the influence of temperature alone, although alpine and polar floras bear a distinct aspect by reason of a combination of conditions of moisture, insolation, duration of the seasons, and course of the humidity.

While temperature is not in itself a direct factor in shaping the general trend of evolutionary development in plants, yet it is indirectly concerned by the influence exerted upon precipitation, and the relation of the amount of the rainfall to the possible evaporation. The great changes in the climatic pattern of the surface of the earth, both in this and preceding periods, produced by whatever cause, may be taken to have affected vegetation chiefly through the humidity and desiccation effects, which not only determined the range and habitats of the species, but also played a predominant part in shaping the general development of the vegetal organism.

It will be profitable therefore to analyze the changes accompanying a modification of a climate toward or away from the desiccation of a region and the response of the flora to such altered conditions of environment. To do this most effectively let us suppose that the rainfall in New York, Pennsylvania, Labrador, Iowa, or Florida were reduced to one-fourth of the present amount by a gradual decrease through a long term of years. In the lower levels of the region affected, the total production of organic matter would be

greatly lessened and consequently the amount of humus would decrease; wind erosion would remove much of this from its place of formation and by this means alone the distribution of many species would be totally altered. The soil moisture would ultimately be so depleted that the surface layers would show as great a proportion as the underlying layers, carrying an excess during seasons of precipitation, a fact that would have the profoundest influence upon the native vegetation, determining not only the habit of the root-systems, the form of the shoot, but also becoming a factor in distribution, and giving a new form to the competitive struggle among the organisms in a locality. The change in precipitation would result in the formation of long outwash, detrital slopes, or bajadas, giving new habitat conditions, and a further differentiation would consist in the surface deposition of soil salts, giving alkaline and saline areas upon which halophytic, or saline plants flourish. The lessened relative humidity would result in modification of foliar surfaces, make necessary for survival special structures in seeds and spores, and would be followed by a more intense insolation by reason of the non-absorption of some portions of the spectrum, and lastly the course of the temperature of the soil would change with the depletion of the humus and the altered water relations.

If desiccation ensued as a result of simple horizontal reduction of the precipitation, in a region with an unbroken surface lying at nearly the same level, the effect would be sweeping, monotonous, and with an almost total absence of selective effect that would mean extermination, or change in a flora *en bloc.* The majority of interpretations of the paleontological record assume such results. It is to be seen, however, that desiccation in a region with diversified topography and great differences in level would result in great differentiation, and if to this reduction is added the restriction of the rainfall to one or two brief seasons or to limited periods a maximum of effect may be expected.

The development of desert conditions in the manner described over a region of any extent would entail the least disturbance on mountain summits, where, by reason of the lowered temperature and the facilities for condensation, the evaporating power of the air would remain lowest. The original, or pre-desert forms would be able

to maintain themselves on such elevated slopes with but little adjustment. Similar survivals might ensue along the lower drainage lines, where the underflow in streamways and washes might support a moisture-loving vegetation as it does in southwestern Africa and southwestern America. So much for survival by localization. A second manifestation would be shown by restriction of seasonal activities. The rate of evaporation on the lower levels might be lessened by lower temperatures during the winter season and at this time rapidly acting annual plants might carry through their cycle of activity, remaining dormant in the form of heavily coated seeds during the warmer, dryer period of the year. Perennials with deciduous leaves might display a coincident activity. This survival of moisture-loving plants in a region of pronounced desert character is most marked, however, in places where the precipitation occurs within definite moist or rainy seasons, such as the great Sonoran desert in which two maxima of precipitation occur, separated by periods of extreme drought. Both the winter and the summer rainy seasons are characterized by the luxuriant growth of broad-leaved annuals, which might not be distinguished from those of any moist region. Some species are active during the summer season, and others during the winter, while a smaller number perfect seeds during both seasons. A number of perennials parallel this activity of the annuals with the result that in the most arid parts of Arizona, according to the unpublished researches of V. M. Spalding, half of the native species are in no sense desert plants, requiring as much moisture for their development as do those of Maryland, Michigan, or Florida. The desiccation of a region is seen therefore not to result directly in the extermination of moisture-loving types, but rather to the reduction of their relative or numerical importance and a limitation of their activities to limited periods, or moist seasons.

Two types of vegetation may be definitely connected with arid conditions, representing as they do the morphogenic action of water which has been a predominant one in the development of the seed-plants. In one form the chief operation has been one of reduction and protection of surfaces. Leaves have been reduced to linear vestiges representing various parts of the foliar organ, branches to spines or short rudiments as in certain Fouquieriaceae,

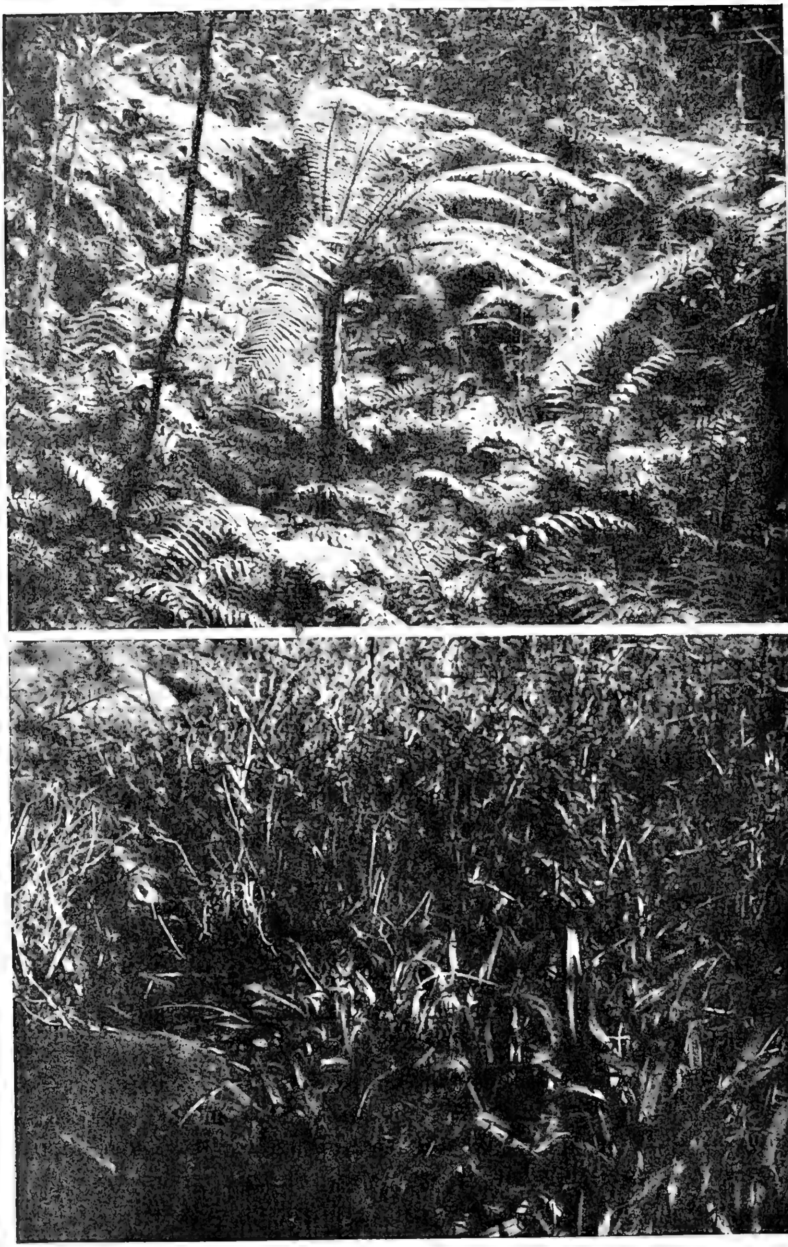


FIG. 3.—(Above) Tree-fern in a moist tropical forest in Jamaica, in which such plants survive. (Below) Dense carpet of borages and other annuals which grow from seed during the rainy season in the Tucson desert. These plants are similar in habit and structure to those of a moist region.

stomata show special constructions, and all parts of the shoot heavily coated and hardened; root-systems have been extended horizontally and the individuals thus isolated, being more or less accommodated to soils containing a large proportion of salts. The spinose, stubby, and switchlike perennials which result from such action are characteristic of low, inclosed desert basins, like the Salton, and those of southern Africa, and central Asia, where the scanty rainfall does not occur within such regular limits as to make distinct moist seasons.

The second form of desert vegetation is one in which the absorptive function has become highly developed and the capacity gained for conserving the surplus water taken up during the moister seasons. The Cactaceae are the most prominent representatives of this type in North America, and some of this group, as well as other species representing a wide range of families, have the capacity for sufficient water to meet the needs of the individual for a decade, while forms are known which might carry out their cycles of reproduction for a quarter of a century by the use of the surplus accumulated within their bodies. Such succulents display not only the reduction of the shoot and of the foliar surfaces together with induration of the epidermis, but have also this capacity for accumulating water and are hence desert plants par excellence, representing the apex of specialization to desiccation.

As a total result of the slow desiccation of any region, therefore, a very important proportion of the flora would consist of moisture-requiring species, or mesophytes, and the remainder would be included in two classes, the spinose forms with reduced shoots and roots, and the succulents with atrophied shoots, but with the additional development of storage structures in some organ of the shoot or root. The total number of species within an arid region is not less than that of the most densely closed tropical area, but the number of individuals is less, the interrelations of the individuals and species are not identical, and the competitive struggle for existence is of a nature widely different from that of a tropical forest. Increase in aridity tends to localization in distribution, and increase in humidity to diffuseness.

Evidence of the existence of xerophytes in previous periods of desiccation is extremely scanty. Calamites and lycopods with a

slender central cylinder and a thick inclosing cylinder of thin-walled tissue have been alluded to in this connection, but these great

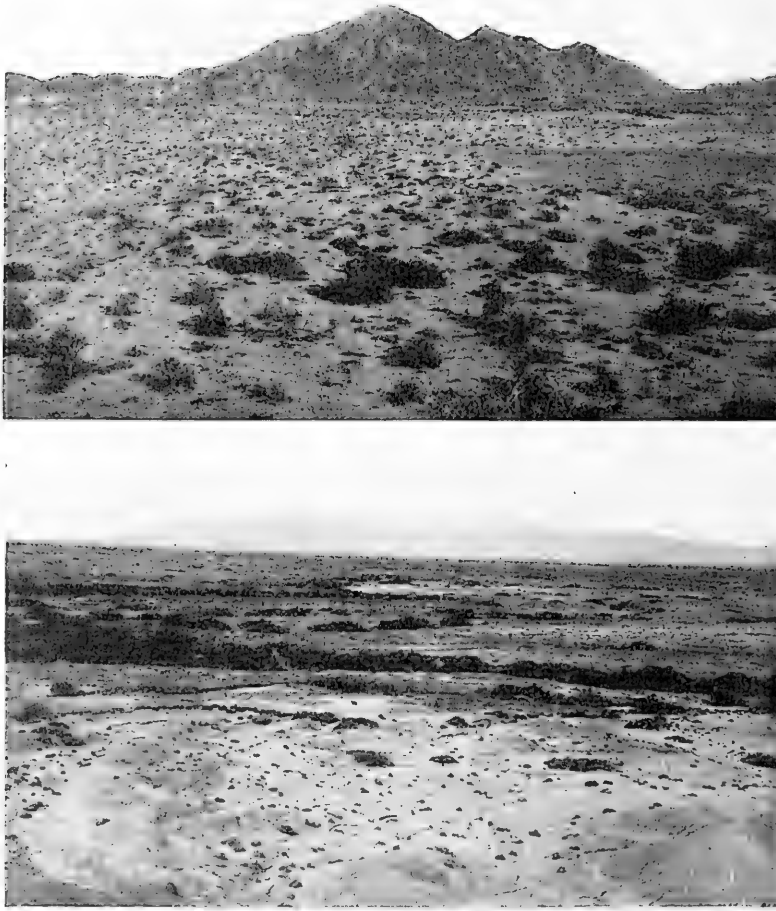


FIG. 4.—Aspect of the vegetation in regions with no well-marked rainy seasons of regular recurrence. (Above) The bolson of Las Vegas, Nevada. (Below) Bajadas of minor range of mountains near the shore of the Gulf of California, San Felipe Bay. The plants comprise spinose forms with very reduced shoots and leaves, which have not developed storage capacity.

sporophytes probably stood in swamps, or at least were hygrophytic in habit, and by the requirements of their separated gametophytic

reproduction could not exist on land areas independently. It is also to be noted that many forms peculiar to swampy areas at the present time display reduced shoots and leaves of a specialized structure due to the action of certain constituents in the substratum, that they are known as "swamp xerophytes" and if brought to light as fossils might give the impression of having lived in an arid climate.

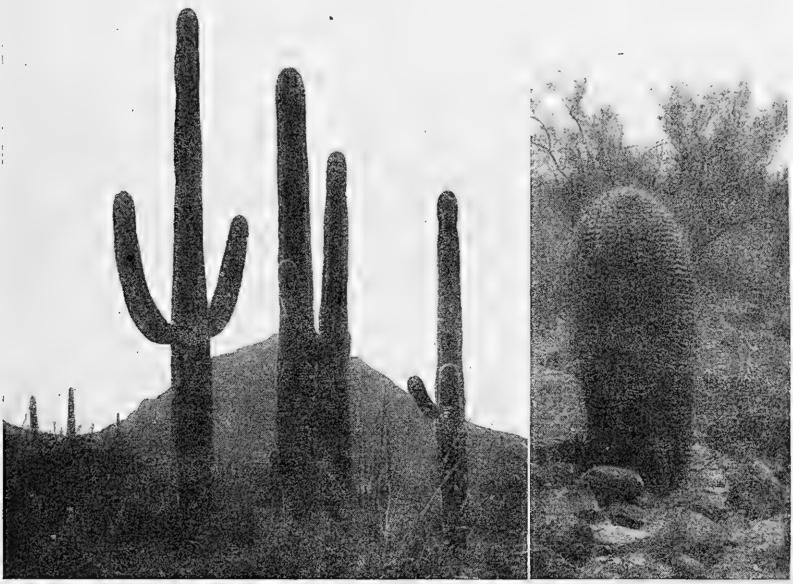


FIG. 5.—Types of plants from the Tucson desert, where two distinct yearly periods of maximum precipitation occur. In addition to the morphological reduction of the shoots and leaves, the capacity for the accumulation and retention of water has reached an enormous development. A group of sahuaros (*Carnegiea gigantea*) on the left; a single bisnaga (*Echinocactus Wislizenii*) on the right. The last-named plant has a supply sufficient for a dozen years' activity in its tissues.

The leaves of conifers very probably represent a specialization adapted to existence in a dry atmosphere, yet it is notable that the greater majority of surviving species live in soils in which the occurrence of moisture is not that of the desert.

The swollen stems of the Bennettitales offer the strongest suggestion of desert forms, and their structure and reproduction would

make possible their maintenance as independent inhabitants of the dry land.

It is true, of course, that desert conditions are not favorable for fossilization, yet many opportunities for such action undoubtedly occur in the carrying and burying action of the torrential floods of desert streamways, while wind-blown deposits might preserve the more indurated forms. Many of these and the skeletons of the Cactaceae would seem well adapted for preservation in this manner, although no remains have yet been uncovered. The view that such forms are of recent origin, within the present period of advancing desiccation, would predicate a very great phylogenetic activity unprecedented perhaps, but by no means impossible.

The actual relationship between plants and their environment is by no means a settled question and since this and related problems are to be discussed in detail at the Darwin memorial session of this meeting, this subject will not be considered here farther than to say that it is unsafe to asssume that any organism has undergone adaptation and fitting specialization in direct somatogenic response to any set of environic factors, and that admissible evidence on such matters is extremely difficult to obtain.[1]

The operations of factors lessening the supply of water to any region would of course result in greater aridity in some places than in others and the movements of xerophytic forms established in these to other contiguous areas dried out later would be a matter in which the direction of the winds, streamways, movements of animals, and position of mountain barriers would play a determining part.

The recession of large expanses of water included in a desiccating region, such as has occurred in the great basins in Utah and Nevada, and in the bolsons to the southward and eastward in New Mexico, Chihuahua, and Arizona would present special conditions. The rate at which the waters of such inland seas might recede, however, would be such that the advance of vegetation to cover the immersed areas would be quite as rapid as that necessary to follow a receding ice-sheet or a change of climate due to any cause. Thus our observations on the Salton Lake show that beaches a mile in width are bared

[1] *Fifty Years of Darwinism.* New York: H. Holt & Co., 1909.

within a year, while the agencies most effective in their revegetation are combined wind action and flotation.

Many areas, such as the central basin of Asia, the American desert, the Eyre Basin in Australia, and southern Africa, offer clear examples of the effect of desiccation upon the vegetation of a region, but when we proceed to the consideration of the probable happenings when an arid region receives an increasing precipitation, our speculations must be based wholly on experimental evidence of the physiological behavior of plants under known conditions.

Here, as in the decrease of the supply of water, no mass movement or extermination of a flora is to be taken for granted. Many highly specialized succulents extremely local in their distribution would undoubtedly quickly perish with the progression of a climate bringing an excess of moisture; alterations in temperature would not exercise such violent action upon plants of wider range, however. That both together might not totally exterminate a type of succulent is shown by the existence of cacti in tropical rain-forests and on the high northern plains of Nevada, Idaho, and Montana. If plants of wider latitudinal distribution are taken into consideration it may be seen that with an advance of polar climate to the southward the extermination of a species in the northern part of its range would be coincident with additions to the eligible area on the southward. If the land area were limited or if mountain barriers intervened, such dissemination would of course be impracticable and the forms involved would soon perish. These features must be taken into account in an interpretation of the flora of the inclosed basin of central Asia, which, so far as the meager information available shows, is extremely poor in the higher succulent desert types, a characteristic also of the Death Valley and of the Salton Basin in North America.

The unfavorable influence of increasing moisture upon the xerophytic forms of a region would also include effects of an indirect character. Soil temperature and moisture relations would undergo great alterations, humus would increase, and other changes would ensue, entailing conditions which their specialized structures would be unfitted to meet. Furthermore, succulent and spinose plants being advanced types, their retrogressive evolution to conform to

moist conditions would be a process resulting in enormous loss of species. Some spinose types would seem to offer the best morphological features for such a change.

Perhaps the most inportant of all of the altered conditions brought about by increasing moisture, however, would be the total transformation of the competitive struggle for existence. Animals would no longer play the predominating rôle as in arid areas. The number of individuals representing the constituent species of a flora would be multiplied a hundred fold, perhaps a thousand fold, and once more the amount of food material offered to animals would decrease their total importance as a factor in selection, while the intensest crowding between roots and between shoots would once more be resumed and horizontal differentiation of associations such as that in forests would ensue.

The element of a desert flora which would respond most readily to ameliorated aridity would, of course, be the hygrophytic annuals and perennials, which had survived the period of desiccation in their refuge of the rainy seasons, and in the moist areas along streamways and on elevated peaks. These would quickly occupy the greater part of the surfaces available for plants to the great intensification of the inter-vegetal struggle for existence. As these hygrophytes survived in the moist situations and the moist seasons of an arid period, so the surviving xerophytes in a moist period would find refuge in restricted habitats on talus slopes, rocks, and sand in which the soil-moisture relations would be best suited to their specialized structure and might display their seasonal activity during a period of the year in which the precipitation was least.

Briefly restating the principal ideas touched upon, it may be said that Chamberlin's prothesis of the planetesimal aggregation of the outer portions of the earth and the attendant conditions, together with current theories as to the catalytic nature of the essential activities of protoplasm, makes possible rational speculations upon the origination of self-organizing matter.

The passing of nitrates, phosphides, carbides, and sulphides into more stable combinations might readily result in the formation of thermo-catalysts, one type of which survived in the later forms of living matter. Similar combinations do not appear to be taking

place at the present time, and their accomplishment experimentally is attended with difficulties not yet surmounted.

The part of the evolution of living matter which may be brought under observation in living forms or preserved material represents very advanced stages and the cell is separated by a wide range of development from the colloidal masses in which self-generating matter first took form. The construction of substances which might use or transform energy other than that of chemical structure represents the first differentiation between the animal and vegetable organisms.

Plants were necessarily confined to aquatic or hygrophytic habitats as long as their history included the free gametophyte, and a land flora became possible only with the development of the sporophyte culminating in the derivation of the seed-plants. In this and in subsequent history the water-relation has played the predominating morphogenic rôle.

The desiccation of a region occupied by a land flora would entail a complex series of changes in climatic and other environmental factors which may be followed by extermination or differentiation of the flora. This differentiation, which would ensue most readily in regions of diversified topography, with an absence of barriers preventing distributional adjustments, would include localizations of habitats, seasonal restriction of activity, and transformation of the competitive struggle for existence from one chiefly among plants to one between plants and animals.

The surviving flora would include an important proportion of mesophytes or hygrophytes, while the arid conditions might be followed by the development of two types of xerophytes, succulents, and spinose forms.

The amelioration of desert conditions would mean a reversal or shifting of various environic factors, the whole favoring the increase in the number of individuals representing the mesophytes, the widening of their habitats, and the institution of the fiercer competition among plants. Such changes would force a retrogressive development on the xerophytes, exterminating many, restricting the range of all, and would result in the survival of a few under conditions wholly foreign and antagonistic to those in which their characteristic qualities originated.

In all attempts to correlate ancient floras and interpret the climate of formations, especially with regard to aridity, the following features are to be taken into account:

Vegetation of diverse lower types might cover moist lowlands, make a profuse growth along streams, or clog extensive stretches of shallow waters in seas and lakes, but only seed-plants could occupy dry land. It is to be borne in mind that the forms representing this advanced type must have constituted a small proportion of the vegetation for a long period after their origination. Their present predominance must be a very modern feature. Furthermore, the dissemination of new forms proceeds somewhat slowly and it is by no means to be taken for granted that the existence of seed-plants, as denoted by fossil remains, is to be taken as an indication that such plants occupied or covered great continental areas. Soil conditions would be a very important factor in such distribution.

The distinction between the vegetation of a region in alternating moist and arid epochs may not easily be made, since as has been pointed out the fossilization of the flora of the Arizona Sonora desert would probably result in material richer in moisture-requiring plants than in xerophytes. The morphological features of the forms preserved would offer the most valuable evidence, and the presence of a single xerophyte among a hundred forms requiring moisture would be of great significance.

The final stages in the differentiation of the land flora, by which spinose and succulent xerophytes have come into existence, seems to have been reached within very recent times. No fossil remains of desert plants have yet been recovered. Some of the forms which have the aspect of xerophytes must have grown in moist regions by reason of their method of reproduction. Some of the cycads and the conifers may be regarded as being most suitable of the older types for existence under arid conditions. The fitness of these plants is due almost wholly to features of the shoot, and the known features of their root-systems offer nothing suggestive of adaptability for the characteristic soil conditions of the desert.

DESCRIPTION OF A PERMIAN CRINOID FAUNA FROM TEXAS

STUART WELLER

The crinoid fauna here described was collected by Professor J. A. Udden in Presidio County, Texas. The specimens are all from the lower brecciated bed of the Cibolo limestone[1] in the east bluff of Sierra Alta creek three miles north of Shafter and one-half mile below Cibolo ranch. The fauna is of interest because it is the first prolific crinoid fauna described from the Permian of this country. The members of the fauna constitute an interesting assemblage of species, most of which belong to the family *Encrinidae* which is restricted in range to the late Paleozoic and the Triassic. The members of this family are characterized by the development of strong articulating ridges upon the distal faces of the radial plates and by the reduction and sometimes by the elimination of the anal plates in the dorsal cup. The only species here described which does not belong to this family is *Hydreionocrinus uddeni*, one of the *Poteriocrinidae* also having strong articular ridges on the radials, but having a full quota of anal plates and a large ventral sack. Besides the species here described there are numerous detached plates in the collection which indicate the presence of nearly as many more species, and many crinoid columns of various sizes and forms, the largest of which attain a diameter of 40^{mm} or more.

In comparing the fauna with similar faunas in other parts of the world, mention must be made of the echinoderm fauna of the upper marine series of the Permo-Carboniferous of New South Wales[2] and that of the Productus limestone of the Salt Range in India.[3] The species here described as *Phialocrinus americanus* must be compared directly with *P. princeps* Eth., from the Australian horizon, and,

[1] Univ. Texas Min. Surv., *Bull. No. 8*, p. 20.

[2] *Mem. Geol. Surv. N. S. W.*, "Paleontology," No. 5, Part 2.

[3] *Pal. Indica*, Ser. XIII, Vol. I, pp. 822–34.

aside from the specimens here described under the generic name *Cibolocrinus*, the only related crinoid with underbasals reduced to three in number is *Tribrachiocrinus* from the same Australian beds. *Cibolocrinus* differs from the Australian *Tribrachiocrinus* only in the absence of the radianal plate from the calyx.

The species recognized by Waagen in the Salt Range of India are somewhat similar to the Texas forms. Two species described under the names *Cyathocrinus indicus* and *C. kattaensis* are clearly not members of that genus and should be referred to some genus, perhaps as yet undescribed, in the family *Encrinidae*. They are very similar in general form to the turbinate species of *Cibolocrinus* from Texas, and are to be distinguished from them only in having the full quota of five underbasal plates. The plates from the same fauna described as *Cyathocrinus goliathus* are very like the similar plates of *Phialocrinus americanus* from Texas and those of *P. princeps* from Australia.

Description of Species

HYDREIONOCRINUS UDDENI n. sp.

(Plate I, Figs. 1–5)

Description.—Dorsal cup saucer-shaped, 42^{mm} in maximum diameter and 12^{mm} in depth. The base deeply excavated for the attachment of the column, all sutures of the calyx, except those between the underbasal plates, situated in groovelike depressions, the surfaces of the plates convex. The underbasal plates form a pentagonal disk 15^{mm} in diameter with a deep, central, circular depression with sides slightly converging toward the bottom, the width of the stem facet is 9.6^{mm}, the width of the depression at its im is 12.5^{mm}, and the depth of the depression 3^{mm}; the distal extremities of the underbasals, beyond the rim of the columnar depression, are short and convex or nodelike. The basal plates large, wider than high, the two anterior ones and the left posterior one uniform in size and shape, being pentagonal with the basal and two distal margins of nearly equal length, the lateral margins not more than one-third the length of the other margins; the outlines of the posterior and right-posterior basals are modified by the introduction of the large adianal, these plates being in the main pentagonal, but

not symmetrically so as are the other three. The radial plates large, about twice as wide as high, pentagonal in outline, marked by strong articular ridges on their distal faces. Radianal plate large, its width about two-thirds its length, its area about equal to that of the adjacent basals, its general outline quadrangular but really pentagonal, the distal face supporting the first tube plate being very short, the proximal angle of the plate in contact with the distal angle of the right posterior underbasal. Anal plate imperfectly preserved in the type specimen, but apparently smaller than the radianal. The first tube plate is incorporated in the calyx at least in its proximal region.

Neither the arms nor the ventral sack of the species have been observed, but accompanying the dorsal cup are a number of large, spatulate, spinous plates which characteristically form the border of the distal surface of the mushroom-shaped ventral sack in this genus. These plates probably represent the same species as the cup, and their form and size is such as to indicate that about 15 of them formed the border of a disk 60 or 70^{mm} in diameter, exclusive of the spinous projections of the plates.

Remarks.—This species is characterized by its great size, the only form at all comparable with it in this respect being *H. kansasensis* from the upper Pennsylvanian of Kansas which is nearly of equal size. It differs from the Kansas species in its smaller underbasal disk, in the deeply excavated base for the attachment of the column, in the slighter contact of the radianal plate with the underbasals, and especially in the outline of the basal plates which are pentagonal rather than triangular.

PHIALOCRINUS AMERICANUS n. sp.

(Plate I, Figs. 8, 9)

Description.—Dorsal cup large, subglobose, the diameter of the type specimen approximately 47^{mm} and its height approximately 30^{mm}. The surface of the plates smooth, all the sutures except those between the underbasals situated in shallow and narrow grooves. Underbasals forming a shallow, saucer-shaped basin which is visible in a side view, its diameter being about 22^{mm} in the type specimen, the stem facet but slightly depressed below the

surface of the plates, its diameter about one-third that of the underbasal disk. Basal plates large, all except the posterior one hexagonal but with the two proximal faces in nearly a straight line and together about equal in length to each one of the other sides so that the general outline of the plates is nearly regularly pentagonal, the height and width of each of these plates in the type specimen is about 24^{mm}; the posterior basal is not complete in the type specimen but it is probably similar to the others except in being somewhat wider and in having the distal angle truncated for the reception of an anal plate. Radials large, pentagonal, wider than high. Anal plate not present in the type specimen, probably quadrangular or pentagonal in outline and resting upon the truncated distal end of the posterior basal between the two posterior radials.

Remarks.—Unfortunately the type and only specimen of this species is imperfectly preserved and somewhat distorted, so that it is not possible to give accurate measurements. The posterior side has been destroyed by weathering so that it is not possible to be certain in regard to the form and position of the anal plate. It is certain, however, that no radianal plate is present in the calyx, but the presence of a small anal plate is more than probable. The posterior basal is broader than any of the other plates of the basal ring, and the two posterior radial plates when projected posteriorly to a width equal to the width of the remaining radials leave a space of about 7^{mm} to be occupied by an anal plate.

The nearest allies of the species are found in *P. princeps* Eth., and *P. konincki* Clarke, from the upper marine series of the Permo-Carboniferous of New South Wales.[1] It differs from *P. konincki* in the convex rather than concave underbasal disk, and from *P. princeps* it differs in its flatter plates with less deeply impressed sutures. From both of these Australian species it differs in its smaller size. In general form the species resembles *Ulocrinus blairi* M. & G., but it may be easily distinguished by the absence of the radianal plate which is very large in that species, and by the relatively broader underbasal disk.

[1] *Mem. Geol. Surv. N. S. W.*, "Paleontology," No. 5, Part 2, pp. 107–10 (1892).

DELOCRINUS MAJOR n. sp.

(Plate I, Figs. 6, 7)

Description.—Dorsal cup large, basin-shaped, with a deep basal excavation, the surface of the plates flat, the sutures flush with the surface, not depressed in furrows. The dimensions of the type specimen are: diameter of dorsal cup, approximately 40^{mm}, height of same 14^{mm}. Underbasals small, nearly covered by the column, situated in the bottom of the basal excavation. Basals large, a little longer than wide, their proximal portion to the extent of nearly one-half of the total length of the plates inflected to form the sides of the basal excavation, the distal portion forming the lower part of the flaring sides of the cup, four of them angular at their distal extremities, the posterior one truncated to support the anal plate. Radial plates large, nearly twice as wide as high, pentagonal in outline, forming more than half of the flaring sides of the cup. Anal plate higher than wide, hexagonal in outline, resting between the posterior basals upon the truncated distal extremity of the posterior basal and extending for nearly one-half its height above the level of the radials, its surface convex along the median longitudinal line and concave transversely along the line joining the two lateral angles. Radianal plate absent.

Remarks.—This species is described from an incomplete dorsal cup, the type specimen being approximately one-half of an individual broken vertically. The portion of the specimen preserved is undistorted and retains the posterior side, so that all the essential characters are preserved. The species is especially characterized by its large size, it being nearly twice as large as the Pennsylvanian species which usually represent the genus. In general form it resembles the common *D. hemisphericus* but has much straighter flaring sides and a proportionally larger anal plate.

DELOCRINUS TEXANUS n. sp.

(Plate I, Figs. 12, 13)

Description.—Dorsal cup basin-shaped, broadly excavated at the base, the surface of the plates convex, the sutures slightly impressed, especially the lateral sutures of the basal plates and at the distal extremities of the same plates. The dimensions of the type speci-

men are: diameter of dorsal cup 20^{mm}, height of same 7^{mm}. Underbasals situated in the bottom of the basal excavation, the diameter of the underbasal disk being about 5.5^{mm}, the columnar facet circular, its diameter about one-half the diameter of the underbasal disk. Basal plates large, longer than wide, the proximal portion forming the sloping sides of the basal excavation, the distal portion sloping outward and upward, the distal extremities angular in all except the posterior plate which is truncated for the reception of the anal plate. Radial plates large, about twice as wide as high, pentagonal in outline, their distal faces furnished with strong articular ridges. Anal plate small, resting between the posterior radials upon the truncated distal extremity of the posterior basal, pentagonal in outline, the distal extremity angular and extending somewhat beyond the level of the radials.

Remarks.—This species is based upon a single very perfect dorsal cup which is similar in size to *D. hemisphericus* (Shum.). It differs from that species, however, in the larger underbasal plates, the broader basal excavation, and in the convexity of the plates, the surface of *D. hemisphericus* being even throughout with the sutures flush with the general surface.

DELOCRINUS EXCAVATUS n. sp.

(Plate I, Figs. 16, 17)

Description.—Dorsal cup basin-shaped, deeply and broadly excavated at the base, the plates a little convex, the sutures impressed in shallow grooves. The dimensions of a dorsal cup are: diameter 20^{mm}, height 7^{mm}. Underbasal plates entirely included in the basal excavation which in the type specimen has a diameter of 8^{mm} at its margin and a depth of 3^{mm} or more, with nearly vertical sides. Basal plates rather large, their proximal borders incurved to form the sides of the basal excavation, the distal extremities angular except the posterior one which is truncated to support the anal plate. Radial plates large, much wider than high, pentagonal in outline, their distal faces furnished with articulating ridges. Anal plates two in number, together occupying the position of the single anal plate which is commonly present in this genus, upon the truncated distal extremity of the posterior basal, the two plates are of nearly equal

size, being separated by a vertical suture nearly midway in position between the posterior lateral margins of the two posterior radials, the distal extremities extend beyond the level of the radial plates.

Remarks.—This species is established upon a single dorsal cup and is characterized by its broad and deep basal excavation with nearly vertical sides, and by the presence of two plates in the posterior interradial area which is usually occupied by a single anal plate. From the single example of the species available for study, it is not possible to determine whether this latter character is normal or whether it is an abnormal condition. If it is the normal condition of the species then the second plate is probably to be interpreted as the first tube plate which is not infrequently present in the dorsal cup of crinoids in which a radianal plate is present. Its presence in this form, however, not associated with a radianal plate is a very exceptional condition and might be considered as of generic value.

ERISOCRINUS PROPINQUUS n. sp.

(Plate I, Figs. 14, 15)

Description.—Dorsal cup basin-shaped, perfectly symmetrical, the sutures between the plates flush with the general surface. The dimensions of the type specimen are: diameter of the dorsal cup 18^{mm}, height of same 9.5^{mm}. Underbasal plates forming a slightly concave, pentagonal disk 6.5^{mm} in diameter, the central portion of which is occupied by the circular columnar facet 4^{mm} in diameter. Basal plates all similar in form and size, hexagonal in outline, but with the two proximal faces meeting in a very obtuse angle and together nearly equal in length to one of the lateral faces, so that the general outline of the plates is pentagonal, the proximal portions of the plates nearly horizontal in position but rapidly curving upward so that the major portion of the plates slopes upward and outward. Radial plates much broader than high, pentagonal in outline, the distal faces bearing well-defined articular ridges. No anal plate present.

Remarks.—This species is established upon a single nearly complete dorsal cup which resembles and is closely allied to *E. typus*. It differs from that species, however, in the somewhat broader basal truncation of the dorsal cup, which is also porportionately higher,

and consequently in the somewhat less divergent sides, also in the shallow concavity of the underbasal disk and in the longer lateral faces of the basal plates.

ERISOCRINUS TRINODUS n. sp.

(Plate I, Figs. 10, 11)

Description.—Dorsal cup turbinate, the sides nearly straight, diverging from the base at an angle of a little less than 90°, the sutures between the plates flush with the general surface, not situated in depressed grooves. The dimensions of the type specimen are: diameter of dorsal cup 14.5^{mm}, height of same 9^{mm}. Underbasal plates five, less than one-half of their proximal extremities covered by the columnar facet, the exposed portions of the plates smooth, forming the flaring sides of a shallow cup. Basal plates smooth, wider than high, hexagonal in outline, their distal extremities angular, the two distal faces longer than any of the others, the two proximal faces meeting in an angle so obtuse that the two together make nearly a straight line. Radial plates much wider than high, pentagonal in outline, the surface curving inward toward the distal margin, each bearing three distinct nodelike tubercles symmetrically arranged, one near each lateral margin of the plate with the third situated lower down on the median line of the plate. No anal plate present.

Remarks.—This species is based upon a single nearly complete but somewhat weathered dorsal cup. In general shape it resembles *E. conoideus* M. and W., from the Pennsylvanian at Springfield, Ill., but it is much larger and is characterized by the presence of the three nodelike tubercles upon each radial plate.

CIBOLOCRINUS n. gen.

Description.—Dorsal cup basin-shaped or turbinate. Underbasal plates three, two large and one small, the larger plates formed by the fusion of the right and left pairs. Basal plates large, the anterior pair hexagonal in outline, the right and left postero-lateral ones pentagonal, the posterior one heptagonal. Radial plates large, wider than high, pentagonal in outline, the distal faces supplied with strong, articular ridges. Anal plate small, resting between the

posterior radials upon the distal extremity of the posterior basal, its distal extremity extending beyond the radials. Radianal plate absent.

Remarks.—The genus *Cibolocrinus* is especially characterized by the reduction of the number of underbasal plates to three, and by the presence of a single small anal plate. The only other genus of crinoids at all closely related to this one having a similar number of underbasal plates is *Tribrachiocrinus* from the upper marine series of the Permo-Carboniferous of New South Wales, but *Cibolocrinus* differs from this Australian form in the absence of a radianal plate.

CIBOLOCRINUS TYPUS n. sp.

(Plate I, Figs. 20–22)

Description.—Dorsal cup basin- or low bowl-shaped, nearly hemispherical in form, the surface of all the plates smooth and the sutures flush with the general surface of the cup. The dimensions of the two type specimens are: diameter of dorsal cup 25.8^{mm} and 22.5^{mm}, height of same 11^{mm} and 11^{mm}. Underbasal plates three, forming a pentagonal disk three of whose sides, those opposite the sutures between the plates, are slightly re-entrant, in the larger of the two specimens whose dimensions are given above the diameter of the underbasal disk is 10^{mm}, the columnar facet circular, moderately depressed, occupying about two-thirds of the diameter of the underbasal disk. Basal plates large, as wide or a little wider than high, all except the posterior one regularly pentagonal in general outline, but the anterior pair are really hexagonal although the two proximal faces are nearly a straight line and together are equal in length to the proximal faces of the other two; the posterior basal is a little wider than the others, heptagonal in outline, being similar to the two anterior ones except that its distal extremity is truncated for the support of the anal plate. Radial plates large, wider than high, pentagonal in outline. Anal plate pentagonal, resting between the posterior radials upon the truncate distal extremity of the posterior basal, it is angular distally, its distal extremity reaching beyond the level of the radial plates.

Remarks.—This species has been selected as the type of the genus *Cibolocrinus,* and is established upon two examples of the dorsal cup. No specimen preserving the arms has been observed. The

species differs from the other members of the genus here described in its subhemispherical form, all the others being turbinate.

CIBOLOCRINUS TURBINATUS n. sp.

(Plate I, Figs. 23–26)

Description.—Dorsal cup turbinate, the sides diverging with a convex curvature from the margin of the columnar facet to the distal margins of the radial plates, surface of the plates smooth, the sutures not impressed in grooves. The dimensions of a complete dorsal cup are: diameter 25^{mm}, height 17^{mm}. Underbasal plates three in number, one small one anteriorly and two large ones posteriorly, a little more than one-third of the length of each plate at the proximal end is covered by the columnar facet which is in the form of a conelike depression, the exposed distal portions of the plates form the flaring sides of a shallow cup. Basal plates large, the right and left postero-lateral ones nearly symmetrically pentagonal in outline, the two anterior ones hexagonal but with the two proximal faces meeting in a very wide angle so as to form nearly a straight line, the two faces together being equivalent to the single proximal face of the postero-lateral plates, the posterior plate similar to the two antero-lateral ones but with the distal angle truncated to support the anal plate. Radial plates nearly twice as wide as high, pentagonal in outline, their surface curving a little inward near the distal margin, their distal faces bearing strong articular ridges. Anal plate small, resting between the posterior radials upon the truncated distal extremity of the posterior basal, widest between the posterior distal angles of the radial plates on either side, probably pentagonal in outline though the distal portion extending beyond the level of the radials is imperfect in the type specimens.

Remarks.—This species is established upon two individuals, both preserving only the dorsal cup. The most perfect one has exactly the same structure of the dorsal cup as *C. typus*, the two species differing in form and proportions. The second less complete example has the sutures between the underbasal plates obscure, but they seem not to have the same position in the first specimen. The normal position for these sutures, in this and other species of the genus, is beneath the posterior and the two antero-lateral basal plates, those

beneath the postero-lateral basals being anchylosed. In the second example mentioned above, these sutures seem to be beneath the posterior and the two postero-lateral basals, so that there are two small plates and one large one formed by the union of the three anterior original underbasals. This is believed to be an abnormal condition in this one individual, since among five examples of the genus in which these sutures between the underbasals can be detected, all except this one have the normal arrangement.

CIBOLOCRINUS TEXANUS n. sp.

(Plate I, Figs. 18, 19)

Description.—Dorsal cup turbinate, the sides diverging with a gently concave curvature from the margin of the colmnar facet, becoming slightly convex toward the distal border of the cup. Surface of the plates smooth, the sutures not impressed in grooves. The dimensions of a dorsal cup are: diameter 21^{mm}, height 14^{mm}. Underbasal plates three in number, large, about one-half their length occupied by the large columnar facet which is in the form of a conical depression in the base of the cup, the distal portions of the plates diverge upward and form the sides of the shallow cup. Basal and radial plates large, similar in form and size to those of *C. turbinatus.* Anal plate small, similar to that in *C. turbinatus.*

Remarks.—This species is closely allied to *C. turbinatus*, but may be distinguished from that species by its much larger columnar facet, and by the concave curvature of the sides of the dorsal cup.

CIBOLOCRINUS SYMMETRICUS n. sp.

(Plate I, Figs. 27–30)

Description.—Dorsal cup turbinate, the sides diverging from the margin of the columnar facet to the distal margins of the radials, the surface of the plates smooth and having the regular curvature of the surface of the cup or sometimes a little convex, the sutures not impressed in furrows. The dimensions of the most complete example are: diameter of dorsal cup 18^{mm}, height of same 13^{mm}. The underbasal plates as in *C. turbinatus.* The basal plates also as in that species except that the posterior one is angular at its distal extremity like the others, not being truncated for the reception of

an anal plate. The radial plates also as in *C. turbinatus* except that the two posterior ones are in contact laterally. The anal plate situated above the radials in a notch between the two posterior radials.

Remarks.—This species differs from the other species of the genus here recognized, in having the anal plate crowded out beyond the radials, giving to the dorsal cup a radially symmetrical arrangement of the plates as in the genus *Erisocrinus* except that the number of basal plates is reduced to three. The elimination of the anal plate from the dorsal cup would ordinarily be considered as a good generic distinction, but in the present case there has been some hesitation in separating these specimens even specifically from *C. turbinatus*. In that species the anal plate is much reduced in size and the only distinction between it and the one here described is that in the present form the anal is still further reduced. The species is based upon three individuals, in two of which the sutures between the underbasals can be clearly recognized.

EXPLANATION OF PLATE

(The figures on this plate are reduced to about $\frac{4}{5}$ natural size)

HYDREIONOCRINUS UDDENI n. sp.

FIGS. 1, 2.—Basal and lateral views of the type specimen; 3–5.—Three views of a spinous plate from the summit of the ventral sack, probably belonging to this species. (Pal. Coll. Walker Museum, No. 13363.)

DELOCRINUS MAJOR n. sp.

FIGS. 6, 7.—Basal and postero-lateral views of the type specimen. (Pal. Coll. Walker Museum, No. 13364.)

PHIALOCRINUS AMERICANUS n. sp.

FIGS. 8, 9.—Lateral and basal views of the type specimen. (Pal. Coll. Walker Museum, No. 13369.)

ERISOCRINUS TRINODUS n. sp.

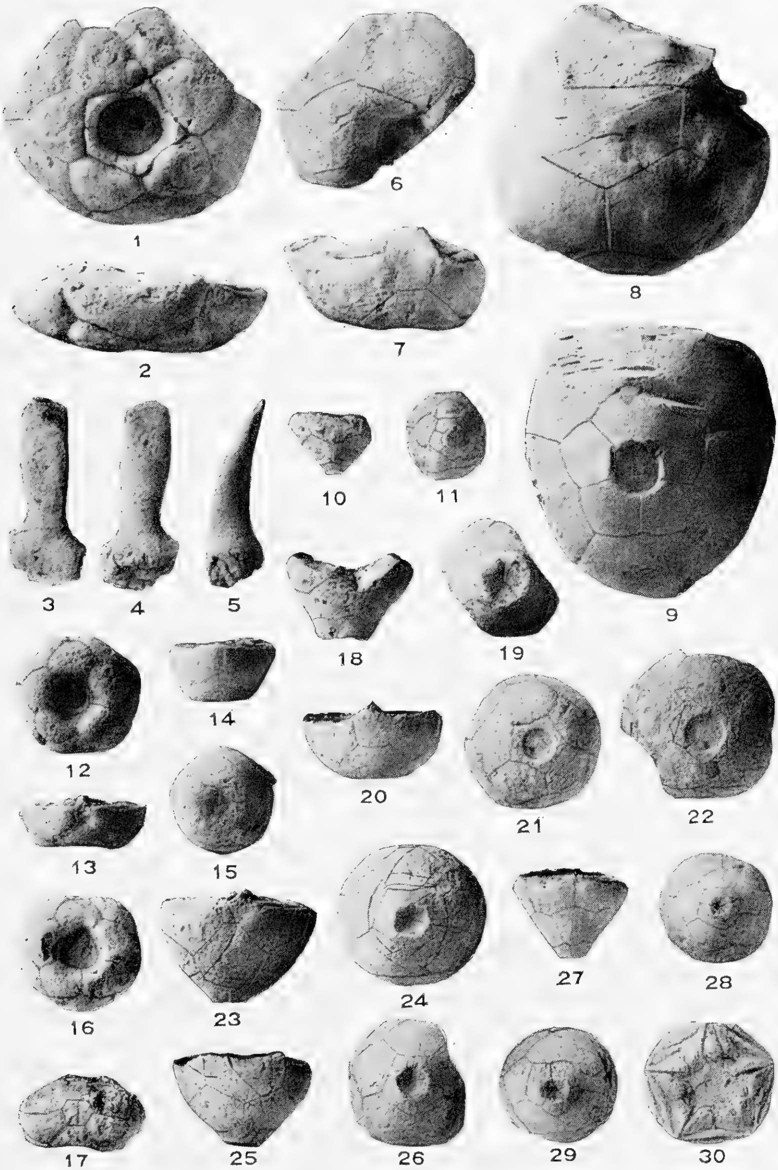
FIGS. 10, 11.—Lateral and basal views of the type specimen. (Pal. Coll. Walker Museum, No. 13368.)

DELOCRINUS TEXANUS n. sp.

FIGS. 12, 13.—Basal and postero-lateral views of the type specimen. (Pal. Coll. Walker Museum, No. 13365.)

ERISOCRINUS PROPINQUUS n. sp.

FIGS. 14, 15.—Lateral and basal views of the type specimen. (Pal. Coll. Walker Museum, No. 13367.)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DELOCRINUS EXCAVATUS n. sp.

FIGS. 16, 17.—Basal and postero-lateral views of the type specimen. (Pal. Coll. Walker Museum, No. 13366.)

CIBOLOCRINUS TEXANUS n. sp.

FIGS. 18, 19.—Lateral and basal views of the type specimen. (Pal. Coll. Walker Museum, No. 13373.)

CIBOLOCRINUS TYPUS n. sp.

FIGS. 20, 21.—Lateral and basal views of one of the cotypes; 22.—Basal view of the other cotype. (Pal. Coll. Walker Museum, No. 13370.)

CIBOLOCRINUS TURBINATUS n. sp.

FIGS. 23, 24.—Postero-lateral and basal views of one of the cotypes; 25, 26.—Lateral and basal views of another of the cotypes. (Pal. Coll. Walker Museum, No. 13371.)

CIBOLOCRINUS SYMMETRICUS n. sp.

FIGS. 27, 28.—Lateral and basal views of one of the cotypes; 29.—Basal view of another of the cotypes; 30.—Ventral view of another of the cotypes, showing the articulating ridges and the small anal plate resting in a notch between the posterior basals. (Pal. Coll. Walker Museum, No. 13372.)

NEW OR LITTLE-KNOWN PERMIAN VERTEBRATES[1]

TREMATOPS, NEW GENUS

S. W. WILLISTON
The University of Chicago

Of the numerous specimens obtained from the famous Permian deposits of northern Texas the past year by the University of Chicago Expedition, none is of greater interest than one represented by a nearly complete skeleton of a new rhachitomous amphibian allied to *Eryops*, discovered by Mr. Paul Miller at Craddock's Ranch, near the town of Seymour. The specimen was found fully exposed on a gently sloping surface, intermingled with the remains of a reptile which seems to be of a new genus of Cotylosauria, which will be described later. At the time of the discovery it was not suspected that more than a single individual was represented by the remains, the bones of the amphibian, save of the skull, being almost wholly inclosed in a more or less weathered mass of hard matrix. Recognizing in the skull some of its peculiar characters, Mr. Miller and I spent several hours in a careful search for all possibly recoverable fragments. Evidently both skeletons had been, originally, nearly complete as preserved in the clay beds, and both were probably close together, but erosion has destroyed or mutilated much of the reptile and some parts of the amphibian. The separation of some of the parts of the amphibian skeleton which had been washed free from their matrix from the remains of the reptile has been difficult. Fortunately, however, nearly all parts of the amphibian skeleton, save the radius, fibula, and most of the tail, were found in anatomical relations in the blocks of matrix.

The incrusting matrix which adhered to most of the bones, while fortunately preserving the specimen from ruin, was very hard, requiring nearly two months of patient work on the part of Mr. Miller to remove. That these specimens, which must have been exposed for

[1] See "The Cotylosauria," this journal, XVI, 139; "Lysorophus," *Biological Bulletin*, XV, 229; "Diplocaulus," *Transactions Kansas Academy of Science* (in press).

a score or more of years, should have escaped the observation of previous collectors in this much searched-over region is remarkable, and only goes to show that these, like most other fossiliferous beds in the West, will never be exhausted. It gives me pleasure to name the species in honor of Mr. Paul Miller, whose keen eyesight and patient labor have brought not only this specimen to light but also many others in the University of Chicago Museum and the American Museum of New York City.

Trematops milleri, *Genus and Species New*

Skull (Figs. 1, 2, 3).—The skull of *Trematops* is remarkable, not only among amphibians, but also among Permian vertebrates, for the association of certain peculiar characters widely distinguishing the genus from any other now known. The chief of these characters are: the possession of a median unpaired rostral opening leading into a palatine vacuity; greatly enlarged antorbital vacuities; a temporal fenestra; and the apparent absence of the parasphenoid bone of the palate. In the skeletal characters, aside from those of the skull, the genus does not differ much from *Eryops*, so far as known, and doubtless the skeletons of each, when fully known, will show a like agreement throughout.

In shape the skull is subtriangular, its width posteriorly being but slightly less than the length from premaxillae to occipital condyles. Its surface is coarsely and rather deeply pitted, but presents no traces of mucous canals that I can distinguish. The face is markedly constricted just in front of the orbits, the facial region showing a slight lateral convexity on the outer sides of the large antorbital vacuities. Back of the orbits the "table" of the skull is broad and nearly flat, perforated by the rather small parietal foramen near its middle. The orbits are oval, their greater diameter oblique to the longitudinal axis of the skull, their borders thickened in front and behind, but thinner above and below, with the plane of their margin looking obliquely forward, upward, and outward. Immediately back of the orbit at its outer part, the table turns downward, forming the anterior bar of the temporal vacuity. The upper margin of this vacuity is perfectly preserved on the left side, but the fragments forming it were not recovered for the right side of the skull. It is thinned, in outline

gently concave and turned outward, and, posteriorly, a little downward, forming the lateral margin of the flat table of the skull. The natural character of the border is beyond dispute, the small pittings

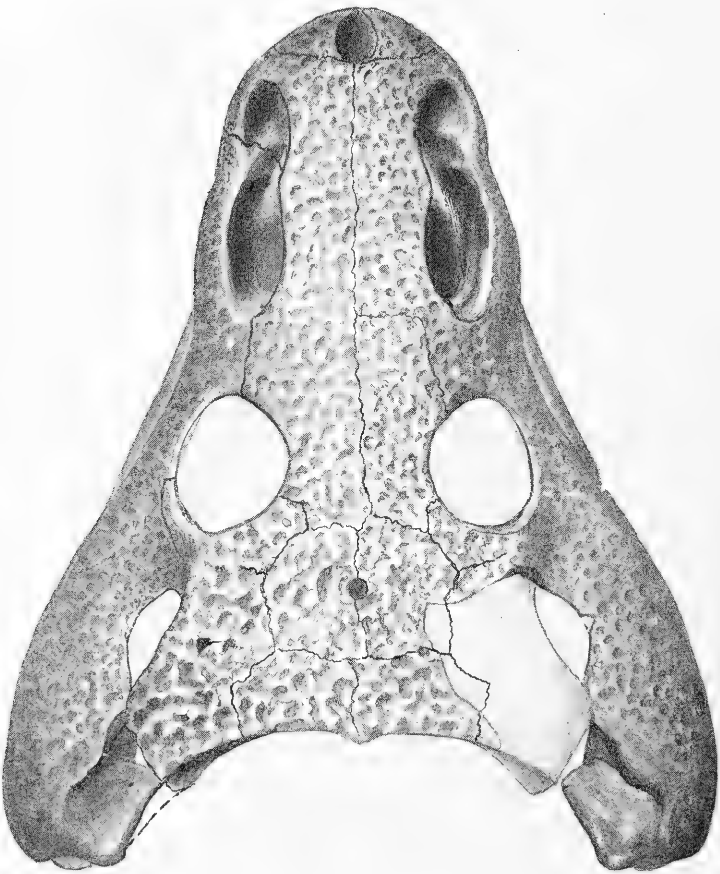

FIG. 1.—*Trematops milleri* Will. Dorsal view of skull; three-fifths natural size.

of the surface continuing quite to the junction of the upper with the lower surface of the cranial bones. There is no possibility of its union, either by suture or fracture, with the lateral walls of the skull. In front the vacuity continues in a shallow, lateral groove, nearly as far

forward as the orbital margin. On the right side the upper margin of the vacuity, as stated, is not preserved, but the natural rounded border of the opening is found on the lower and partly on the front side, giving, with the left side, practically the outline of the vacuity throughout, save at the narrowed posterior end. The cavity was oval in shape, about twenty millimeters in length, looking outward, and a little upward and forward. There remains the bare possibility that the enlarged vacuity was connected by a slender and sinuous isthmus with the outer posterior margin of the skull, but I do not think so. In position, it is seen that the fenestra is nothing more nor less than a greatly elongated and closed epiotic notch, and this interpretation is confirmed by the disposition of the bones on the under, palatal side of the skull. Other genera of stegocephs have the epiotic notch closed posteriorly, but I know of none in which it extends nearly so far forward as it does in this genus. As an epiotic vacuity it conveys the suggestion that the origin of the lateral temporal vacuity in the double-arched or saurocrotaphic reptiles has arisen, not by a natural trephining of the skull wall, but by the inclusion of an epiotic notch. From the fact that the so-called squamosal bone borders the vacuity above, it would hardly seem to be homologous with the superior temporal fenestra. However, it is by no means sure that the superior bone is the real homologue of the squamosal of the higher animals. I have followed Baur in so considering it, but I by no means believe that its squamosal or supratemporal character has yet been demonstrated.

The sutures, for the most part, in the skull are indistinguishable or distinguishable with difficulty from the cracks. On the upper surface of the table, however, they are very conspicuous, as shown in the illustrations. The parietals, it is seen, are rather small bones, uniting by a transverse suture with the so-called supraoccipitals behind.[1] The shape of the postfrontals is clearly shown, but the postorbitals are indeterminable. Nor can I make out the limits of the

[1] It has long been known that these so-called supraoccipitals of the stegocephalan and cotylosaurian skulls are not the real supraoccipital of the mammals and higher reptiles, but are membrane bones. Perhaps the best name that has yet been applied to them is that of Broom—the postparietals. In a later paper I shall figure both the cartilage supraoccipital and the membrane supraoccipitals in the same specimen, not even suturally united.

epiotics and "squamosals" or "supratemporals," though the two bones very clearly form the outer part of the table. The frontal bones terminate a little in front of the orbits by a nearly transverse suture,

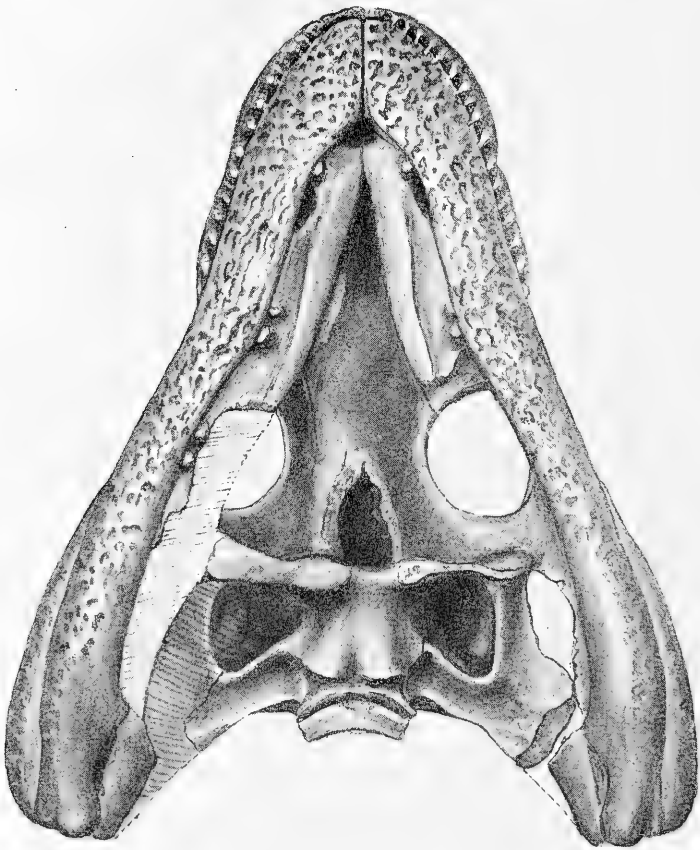

FIG. 2.—*Trematops milleri.* Palatal view of skull; three-fifths natural size.

and, of course, the nasal bones form that portion between the antorbital vacuities, as far forward as the rather small premaxillae.

At the very front of the rostrum there is a rather small, but perfect, median, unpaired vacuity leading into a foramen in the middle of the palate below. I am at a loss to say what its real nature is. If not a

median narial opening, I cannot see why there should be a palatal opening below it. It is not for the passage of teeth, as in some labyrinthodonts. A median opening is not unknown among the Stegocephala. *Dasyceps*, from the Permian of Kenilworth, has a large, elongate opening between the nasals, and *Acanthostoma*, from the Rothliegendes, has a moderately large median vacuity between the large nasals and the premaxillae.

The greatly enlarged and elongated openings on the sides of the face in front of the orbits are, in part at least, merely antorbital vacuities; of this there can be no doubt. The anterior portions, however, seem to be the real nares, in position like those of *Eryops*, and opening into a vacuity at the outer side of the palatine and vomers of the palate. A flattened or concave bone is seen in the right fossa, directed obliquely backward. It may be a turbinated bone.

The occipital condyles are parial, the gentle concave articular surfaces looking backward, a little downward, and toward each other. A specimen of *Eryops* in the collection shows, I think clearly, a transverse suture a little in front of these processes separating them from the part in front which I believe to be the basisphenoid, and just back of a pair of flattened or spoon-shaped processes, corresponding to the hypopophyses of the reptilian basisphenoid and occipital region. In front of these processes the bone is gently concave from side to side. In the middle in front there is a rounded heavy margin, which shows no traces of a bony prolongation, as in *Eryops*, into the median parasphenoid. On either side in front the basisphenoid turns downward in a thickened process, quite as in *Eryops*, to articulate with the pterygoids. On either side, posteriorly, from the basioccipital processes a groove runs outward and upward, bounded in front and behind by bars of bone. At about 30^{mm} from the middle line this groove turns at an acute angle forward nearly parallel to the median axis of the skull to terminate at the outer end of the pterygoids, and leading into the temporal vacuity. The bone containing this groove shows at its inner extremity a distinct suture separating it from the occipital and basisphenoid. It is doubtless in part at least the paroccipital.

The pterygoid, from the basisphenoid articulation, turns trans-

versely outward as a vertical plate, ending in a sutural articulation, just back of the orbit, with the anterior end of the bony ridge bounding what I believe to be the otic groove. The plate does not seem to reach quite to the roof of the skull in its middle part. The under margin of this plate is widened a little antero-posteriorly externally. Its outer extremity is lost, but it doubtless unites with the palatines at the outer side of the palatal surface, and probably sends back a posterior process at the sides to connect with a broken extremity of a flat bone on the inner side of the quadrate. The attachment of this bone, or of a separate transverse bone, is shown by a broken edge turned downward a little below the plane of the palatines to abut slightly against the upper inner margin of the mandible. There is no indication of a median parasphenoid prolongation in front of the basisphenoid, but a broken surface of a bone forming the brain case for the cerebrum may

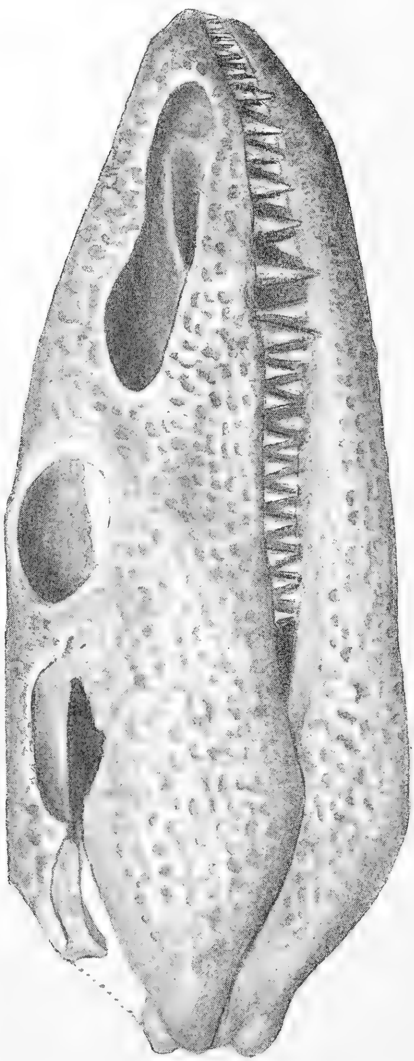

FIG. 3.—*Trematops milleri*. Side view of skull; about two-thirds natural size.

perhaps represent what is left of the parasphenoid, which must in this case be far above the plane of the palatines and closely applied to the under side of the brain and its rhinencephalic anterior prolongation. The palatines, or the combined palatines and pterygoids, form a narrow horizontal shelf along each maxilla. The inner part of this shelf is thickened, so that its median border forms nearly a flat surface directed inward and downward, and separated by a depression or groove from the outer palatinal surface. Probably this portion represents the anterior prolongation of the pterygoids, but I can distinguish no trace of a suture between the two portions. The palatal shelf of the left side was crushed against the opposite side in the specimen, lying quite in contact nearly as far back as the orbits. There could not have been any median parasphenoid between the two parts, the angle anteriorly being acute and the palatines or vomers meeting and coming closely in contact anteriorly. The internal nares are oval vacuities situated nearly below the anterior part of the lateral facial vacuities. Just in front of the opening on each side and close to the margin of the mandible, as articulated, there is a large tooth, doubtless situated upon the vomer. There are four large teeth upon the palatines, also attached so that they come closely in contact with the inner side of the mandible in the closed mouth. These teeth are in two pairs. The first pair, of which the anterior one is the smaller, are situated a little in front of the orbit, the apex of the larger tooth reaching nearly to the lower border of the mandible. It has a length of 22^{mm}, with a width of 12 at its base. The posterior pair, of nearly equal length, measuring about 12^{mm} each, are also closely applied to the inner side of the mandible a little back of the middle of the orbit.

Teeth.—There are twenty-five or twenty-six teeth in each of the upper series, and about the same number in each mandible. Six of these, of rather small size, are attached to the premaxilla in front of the lateral narial opening. The longest measures 8^{mm}. The largest of the maxillary teeth are situated back of the middle of the narial vacuity, two of them measuring 14 and 15^{mm} in length, by 5^{mm} in diameter at their base.

The mandible is rather slender, with a short symphysis, where the somewhat expanded bones form a shallow but short trough, the

two together below gently convex from side to side. The lateral outlines of the mandibles from below have a gentle concavity near the middle, curving rather strongly inward behind. The inferior margin of the jaw turns upward behind rather abruptly, and is narrowed from side to side. The sutures of the mandible are not certainly distinguishable. Posteriorly the articular projects but very little beyond the quadrate.

Vertebrae (Figs 4 ff.).—The remains of twenty-three vertebrae are preserved in an uninterrupted series connected with the occipital condyles. Of these the sixteenth, seventeenth, eighteenth, and nineteenth are represented by their arches only, their centra lost from the block of matrix wholly or for the most part. As far as the fifteenth the hypocentra lie closely associated, save for a twist at the seventh, in a somewhat sigmoid curve, with the spines vertical or nearly so. At the sixteenth the column was twisted so that the spines lie horizontally to the right, the left leg with its parts but little disturbed lying for the most part upon or at the right side of the column with its ventral side uppermost. The femur is much flexed upon the leg and its head turned across and above the posterior vertebrae. At the end of the twenty-third, or rather in the twenty-fourth, another break occurs in the series as preserved in the matrix. The succeeding block of matrix includes four vertebrae, and was much worn. Erosion of the projecting ends of the series in the two blocks prevent their positive union. The first eroded vertebra of this series bears the left sacral rib, and, lying above it, the proximal part of the left ilium. By joining the two eroded ends of the series with the acetabulum lying uppermost, the head of the femur nearly fits into it. It is certain that the leg suffered no disturbance whatever after the decay of the flesh covering it, save a slight rotation of the tibia outward and the displacement of the fibula. It clearly occupies its proper position as regards the vertebral column, from which it follows there could not have been more than one or two vertebrae lost.

The axis is much broader from side to side than the following vertebrae, and is very short antero-posteriorly. Its large articular surfaces fit closely the condyles of the skull. Its posterior margin below is nearly parallel with the anterior. I can discover no indications of separated pleurocentra, though such may have existed. Its

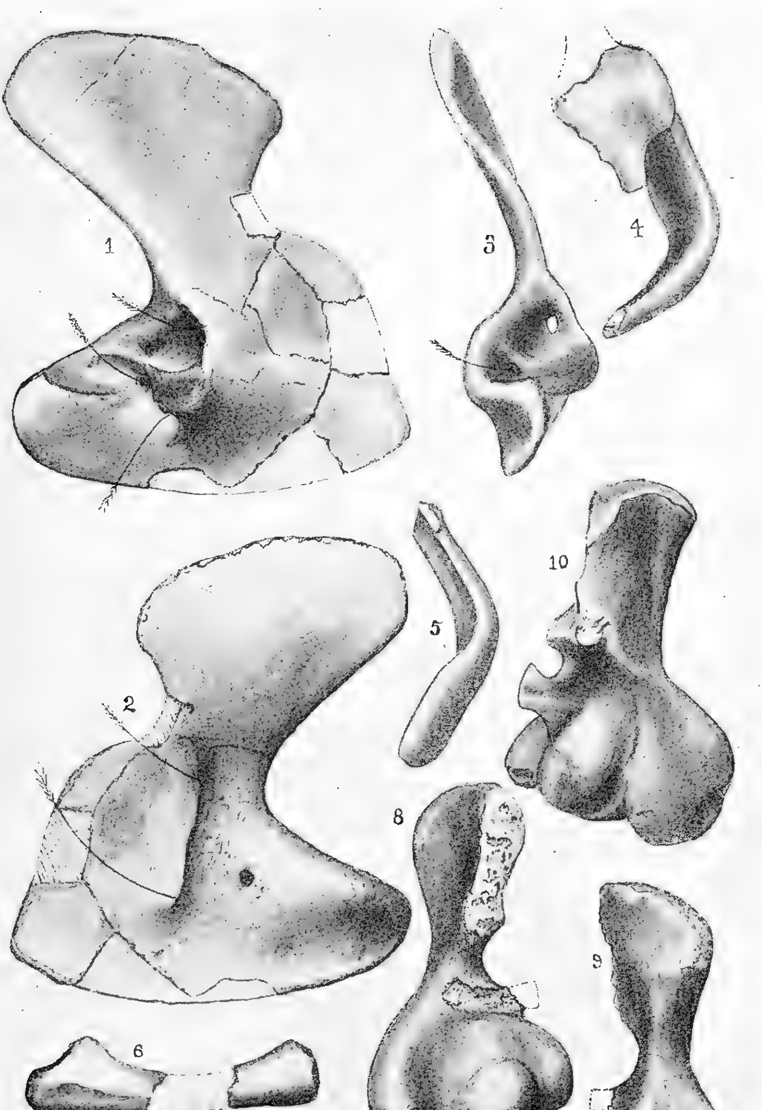

FIG. 4.—*Trematops milleri.* 1, right coraco-scapula, from without; 2, the same, from within; 3, the same, from behind; 4, interclavicle and right clavicle, from above; 5, right clavicle, from behind; 6, left ulna, from within; 7, the same, from without; 8, left humerus, from in front; 9, the same, from behind; 10, *Eryops*, right humerus, one-third natural size. All figures, except as noted above, two-thirds natural size.

separated neuropophyses are vertical and slender, widely separated from each other above by the massive spine of the second vertebra. Above the middle of each neuropophysis there is a small posterior zygapophysis for union with the second vertebra. The hypocentrum of the second vertebra is much smaller than the following ones, transversely oval in shape. There may be pleurocentra here also, but I cannot distinguish them. The spine is very massive above, with strong rugosities posteriorly, broad from side to side, with the slender neuropophyses of the axis lying in contact with it in front. The hypocentra of the succeeding vertebrae are almost identical in size and shape, scarcely varying a millimeter in length or breadth, though those of the sacral region may be a little stouter. Where best preserved they show a flattened surface on the under side separated by a ridge from the sides, though in others this flattened part seems to be merely a rounded keel. Many of the pleurocentra have been dislodged, but such as are in position in different parts of the column are alike in shape and in attachment, all rather smaller than the anterior or mesial ones of *Eryops*. The longer neuropophysial attachment is with the succeeding arch. These attachments of the pleurocentra leave only a small surface on the hypocentrum for union with the arch, which, here as in *Eryops*, for the most part is more closely united with the pleurocentrum of the preceding vertebra than with that following the arch, to which it presumably belongs. Complete spines are present in several of the anterior and posterior vertebrae, but lack their distal extremities in most of the others. As is the case with the hypocentra and pleurocentra they are all nearly alike throughout in thickness and length. They are a little compressed from side to side, and slightly thickened at the upper extremity. Anteriorly the spines are nearly vertical, but posteriorly they are slightly inclined backward. The transverse processes, springing from the arch, are also, so far as can be determined, nearly alike throughout the presacral series. They are stout, slightly compressed vertically, and are directed nearly straight outward, or a little backward. The zygapophyses are rather better developed than in *Eryops*, and are not placed so closely together, their articular facets at an angle of about forty-five degrees. The transverse process for the sacral rib is very stout and heavy, with its large articular facet directed

outward and downward. There is but one true sacral vertebra, though the transverse processes of the vertebrae immediately preceding or following the sacral are heavier than elsewhere. Altogether the vertebrae of *Trematops* are very much like those of *Eryops*, the pleurocentra anteriorly somewhat smaller, the transverse processes somewhat longer and stouter, and the zygapophyses a little better developed. Of the caudals, save the two connected with the sacral vertebrae, only one small block of matrix containing several more or less confused bones of the distal part of the series is preserved. The chevrons are stout and short, united above in a heavy hypocentral mass which is excavated in its middle for the notochord. In front of one of the preserved chevrons there is a pleurocentrum which seems to have separated the hypocentra ventrally.

The ribs are everywhere short. For the first nine or ten vertebrae they are much dilated, both proximally and distally, with the distal portion twisted somewhat from the plane of the proximal. They have a slight but distinct curvature. In the region of the fifteenth vertebrae the ribs are much smaller, with the proximal portion less dilated, and with a longer, rounded shaft. The first rib preserved in the matrix has its head closely applied to the side of the second vertebra. The attachment of the ribs, at least anteriorly, was to both the transverse process of the neurocentrum and the pleurocentrum or hypocentrum, though no articular face is visible. The sacral rib is quite like that of *Eryops*. It has a broad, stout, proximal portion articulating chiefly with the transverse process, but also below and in front with the hypocentrum or region between the hypocentrum and pleurocentrum; the distal part is much flattened and expanded, and is curved downward.

Pectoral girdle and extremity.—Scapula-coracoid (Fig. 4). The right side of the pectoral girdle was found inclosed in the matrix close to the skull, lying on the sides of the anterior vertebrae. The preserved parts are very complete. Some fragments of the border of the coracoid, and the tip of the clavicle only are missing. The united bone, on the whole, resembles that of *Eryops*, save especially in the absence of the cleithrum, which is large and stout and closely applied to the front border of the scapula in *Eryops*. The scapula is much expanded above, and is flattened, a little

thickened posteriorly, the planes of its outer and inner surfaces directed a little inward anteriorly. The scapula narrows rapidly to within a short distance of the glenoid fossa, and then is widely expanded antero-posteriorly for the coracoids. That portion corresponding to the procoracoid of the allied reptiles is a little thickened, nearly flat, and directed somewhat toward the visceral side. The lower anterior angle is nearly rectangular, and the mesial border of the whole bone is gently convex in outline, and is somewhat thinned. Posteriorly the rather narrow coracoid projects strongly backward, its narrowed extremity thickened and strongly curved toward the visceral side. The deep glenoid cavity is directed upward, backward, and outward. Above, the thickened hind border of the scapula divides, inclosing between its two branches a rather deep non-articular fossa. The anterior or external branch continues downward in the same plane and direction as the scapular border, ending in a subtriangular, articular facet looking backward and outward. The end of the humerus lay in immediate apposition with this facet. The posterior continuation of the scapular border, the thicker of the two, curves inward and backward, in a strong, nearly semicircular sweep to near the extremity of the coracoid. Between these two divergent borders, there is a deep cavity or fossa, evidently no part of the real glenoid fossa, pierced by a large foramen or fenestra at its bottom. Just below the lesser ridge which bounds this fossa posteriorly from the glenoid cavity, running from the internal angle of the humeral facet upward and backward, and near its middle part, there is a second foramen, which opens on the convex surface of the inner side of the bone. A third foramen is seen below the humeral facet, opening on the inner side at the lower end of the vertical flexure. This must be the true supracoracoid foramen, through which the scapula-procoracoid suture doubtless passes. The true glenoid fossa is limited below posteriorly by a strong declivity. The inner surface of the scapula above, like the exterior, is nearly flat, the lower surface convex in front. Just back of the glenoid cavity and corresponding to the vertical margin of the outer side, the bone on the inner side turns abruptly outward, save on the lowermost portion, bounding in front a posterior cavity into which opens the supraglenoid and the supracoracoid foramina, above and below, as shown by the arrows in

the figure. In front of the border the surface of the bone is strongly convex from above downward, and somewhat so from side to side. This surface is pierced near its middle by the glenoid foramen.

No sutures are visible distinguishing the bone into its three elements. As regards the cleithrum, there is a total absence of all indications of such a bone as occurs in *Eryops*, either on the upper or anterior border (Fig. 7).

Clavicle and interclavicle.—The right clavicle was found in the matrix nearly in its anatomical position, its upper end only gone. It is very small for an amphibian, and has lost every trace of the pittings so characteristic of the stegocephalan clavicles on its outer surface, though not unlike the clavicles of *Eryops*. (See Williston, *Kansas University Quarterly*, VIII, 185, Pl. XXIX, Fig. 2.) The clavicle is bent near the middle nearly at a right angle, and somewhat twisted. The proximal part, underlying the interclavicle, is but moderately expanded—less so, in fact, than in the contemporary reptiles, and not twice the width of the distal part. Its anterior border is thickened, its posterior, somewhat everted portion is thin. The scapular extremity is lost, but there is some, though doubtful, evidence of the possession of a small cleithrum, shown by a fragment of a small bone apparently attached to it. The greater part of the interclavicle is present in the specimen, lying on the under side of the procoracoid angle of the scapular bone. The bone is flattened and expanded transversely, with a short lateral projection on each side, and a thin but broad anterior margin. In the middle, posteriorly, the bone is slightly thickened, but there was no median posterior elongation, as in the reptiles. The interclavicle is remarkable for its small size, and thinness, as well as for the entire absence of external pittings. As a whole, the clavicular, as well as the scapular girdle is markedly reptilian in character, far more so than in any other known amphibian.

Humerus.—Lying closely articulated in the right glenoid cavity was the proximal inner side of the right humerus as far as the median constriction. The outer proximal part had been eroded away, and of the distal portion only the outline of the bone, and the inner distal part remained. Of the left humerus almost precisely the same proximal part was found loose in the wash, together with the distal half, with the exception of the inner distal part, that part left in the

matrix of the right humerus. The two bones hence give the characters of the complete humerus with the exception of the proximal outer part. The humerus resembles not a little that of *Eryops*, a figure of which, more reduced, I have given for comparison (Fig. 4), although a little more slender, as are, indeed, all the bones of the extremities. The two expanded extremities are twisted at an angle of about sixty degrees, the shaft between them abruptly and much constricted, about 8 by 10^{mm} in diameter. The proximal anterior face is somewhat concave. The distal portion has a large rounded radial convexity on its outer side, above which, separated by a groove at the outer side, is a small process, evidently quite like that of *Eryops*. The inner condyle is somewhat thickened; the entepicondylar margin is convex from above downward, but wholly without an epicondylar foramen, such as is present in the related genus *Acheloma* Cope.

The two extremities of the right ulna were found free in the wash, distinguished from the reptilian ulna found with the specimen by their much smaller size and the less produced olecranon. I have figured them in the plate (Fig. 4), separated by the same relative distance as those of the ulna of *Eryops*. The proximal portion is convex on the inner side, thinned above and below. The outer side is concave for the radius, with the humeral articular surface, or sigmoid cavity, showing more from that side. The olecranon is rugose. The distal extremity is but slightly expanded, a little thickened in the middle at the end, gently convex on the dorsal, and concave on the palmar surface.

The extremities of what I believe to be the radius are among the fragments recovered in the wash, but the present impossibility of distinguishing them from the reptilian remains renders their description inadvisable. I have outlined the bone in the restoration from *Eryops*.

A mass of matrix containing nine carpal bones united in their proper relations was secured. Their distinction from the reptilian specimen is assured by their smaller size, and the determination of the carpal bones in that specimen. Their relative size and position, as I determine them, will be seen in the restoration. It is evident that two of the proximal bones are missing, and they are shown in shaded outlines in the figure.

Pelvic girdle and extremity (Fig. 5).—The left ilium was preserved attached to the sacral vertebra and rib, nearly or quite in normal position, but considerably eroded on its outer surface. The acetabular portion of the same side, found loose, shows also considerable erosion of the surface, and the precise connection with the ilium worn off; the symphysial portion also of both ischium and pubis is wanting. The ilium resembles somewhat that part in *Eryops*, but is broader, less elongate, and thinner. The acetabular part is quite similar to that of *Eryops*, and it is quite probable that the missing portion below will be found also like that of *Eryops*. The acetabulum is large and shallow, with a thickened rim in front, a rounded protuberance at the upper part, and a thickened margin at the lower posterior part. The pubic foramen below the anterior part of the acetabulum opens on the inner side toward the front margin.

Femur.—The left hind leg (Fig. 5, 1) is preserved almost completely, and with but little disturbance of its parts, lying partly upon, partly at the right side of the vertebral column, its ventral side uppermost, the femur much flexed and inclined over the vertebrae to meet the acetabulum, which was lying nearly horizontally. The femur resembles in miniature that of *Eryops*. Its proximal extremity is thickened, transversely convex above, much thickened on the inner side, less so on the outer, and with a shallow fossa behind, externally. The shaft is much narrowed from side to side at the lower third. The "lesser trochanter" is robust, beginning about one-third the length of the bone; its face is oval in outline, with a longitudinal groove, and is directed proximally and ventrally. The "linea aspera" continues the trochanter as a high, thin longitudinal crest, curved somewhat outward, to end near the beginning of the last fourth of the bone, in the upper part of the popliteal surface, about midway between the lateral margins. The distal extremity of the femur is expanded to the full width of the proximal extremity, chiefly on the inner side, the internal border of the bone forming a deep concavity above, while the external border of the bone is gently concave on the middle two-fourths, the first and last fourths gently convex in outline. The distal border of the inner condyle is nearly transverse and straight, thickened internally; the external condyle is narrow, and greatly expanded antero-posteriorly, so that the distal articular surface somewhat resem-

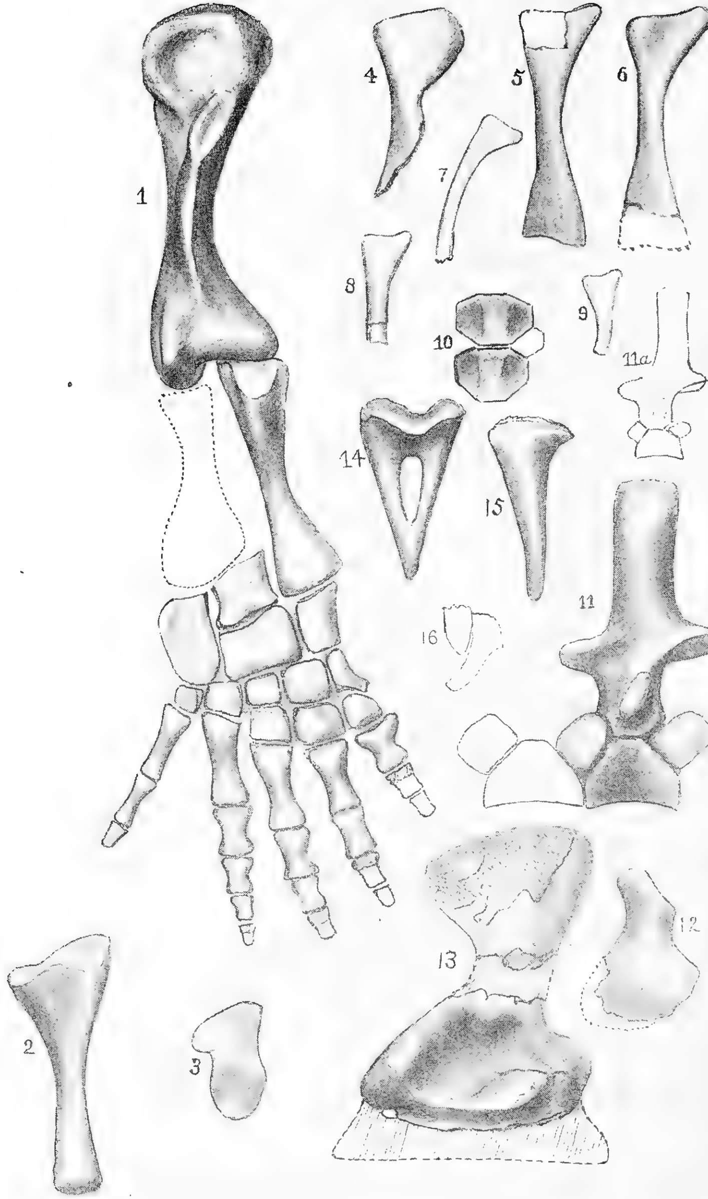

FIG. 5.—*Trematops milleri.* 1, left hind leg, ventral or plantar side; 2, left tibia from without; 3, the same, proximal surface; 4, right second rib; 5, right seventh rib; 6, right eighth rib; 7, seventeenth rib; 8, nineteenth rib; 9, twenty-third rib; 10, twelfth and thirteenth hypocentra, from below; 11, ninth vertebra, from the side, about four-thirds natural size; 11*a*, the same, about two-thirds natural size; 12, left sacral rib, from above; 13, left innominate, from without; 14 and 15, chevron, from behind and the side, about four-thirds natural size; all figures, save as noted, about two-thirds natural size.

bles an italic letter *L*, with the intercondylar groove in front deep, the popliteal groove shallow. In front, the outer border is convex to the articular surface for the fibula, and the articular surface as a whole is directed ventrad at an angle of about forty-five degrees from the long axis of the femur, and also outward at an angle of about twenty degrees; the articular surface also extends proximad on the ventral side so as to permit a considerable degree of flexion, while complete extension would have been impossible. The considerable depth of the pelvic symphysis raised the acetabular surface some distance from the ground, and doubtless the knee was constantly flexed to a considerable extent.

The tibia is preserved in the matrix in articulation with both the femur and tarsus, but rotated somewhat upon its outer side. Its proximal extremity is much expanded, antero-posteriorly, and also somewhat from side to side. Its articular surface for the femur is slightly concave, sloping obliquely backward and outward from the long axis. Its proximal part in front is broad for the insertion of the stout muscles of the intercondylar groove, while a large surface posteriorly also gave insertion to the flexor muscles. The middle of the shaft of the bone is slender, and nearly circular in cross-section, from which place the bone becomes gradually broader to the distal end, which is thickened and broader from side to side than from before back. The outer border of the bone, as a whole, is nearly straight, or gently concave; the inner border is deeply concave.

As already stated, the fibula was dislodged from its position. Lying close by the inner side of the tibia, is a flattened bone, imperfect at one side, which is evidently the distal extremity of a fibula. The part preserved is remarkably broad, much thinner on its outer side, thickened, shaft-like on the inner, where broken off. Distally it shows two thickened, apparently articular borders separated by a thinner, non-articular margin.

The tarsus and foot lie almost perfectly in position, the tibiale slightly turned outward by the rotation of the tibia, and the fifth toe partially turned under the fourth and third. Lying as they do upon the sides of the fourteenth, fifteenth, and sixteenth vertebrae, the bones are somewhat uneven, because of the rugosities. There are twelve tarsal bones, three in the proximal, four in the middle, and five in the

distal row, a number found by Baur in *Archegosaurus*, but otherwise unknown among air-breathing vertebrates. Of the proximal row the tibiale is elongate, a little broader proximally, with a thickened, rounded internal margin, articulating proximally with the tibia, distally with the first centrale, and internally with the second and third centralia. The intermedium is large, with a thickened, oblique face for union with the fibula proximally, a free rounded border opposite the distal part of the tibia, articulating distally with the large centrale, and externally with the fibulare, leaving, however, a small opening for the passage of vessels. The fibulare is elongate antero-posteriorly, and is rather broad; it articulates proximally, on the upper side, with the fibula, internally, above, with the intermedium, distally with the fourth and fifth distalia, and between them and the intermedium with the large centrale. The proximal centrale is one of the largest bones of the tarsus; it is somewhat broader on the inner than on the outer end, articulating proximally with the intermedium, internally with the tibiale, externally with the fibulare, and distally with the two outer centralia. The innermost of these is the smallest, articulating between the tibiale and the first distal, and, on the outer side, with another centrale. This is an unusual position for a centrale, and I have endeavored to find in the small bone some evidence of extraneous origin, but am quite convinced that it really belongs in this place, as otherwise the space it occupies must have been unossified. The median distal centrale is the largest of the three distal centralia, and is nearly square in outline; it articulates proximally with the tibiale and proximal centrale, on either side with a centrale, and distally with the second distal. Of the distal, the second is the largest and the fifth is the smallest, the third and fourth smaller than the second. Each distal supports its own digit exclusively.

The digits are, it is seen by the figure and the restoration, very short and heavy. The first metatarsal is very characteristic in its broad and short form, resembling more a proximal phalanx, broadly expanded proximally and much constricted in the middle. At its distal extremity there is a fragment of the first phalanx in articulation, the remainder lost. The width of this fragment would indicate the possibility of a second phalanx of very small size. The second metatarsal is much longer than the first, its proximal extremity less

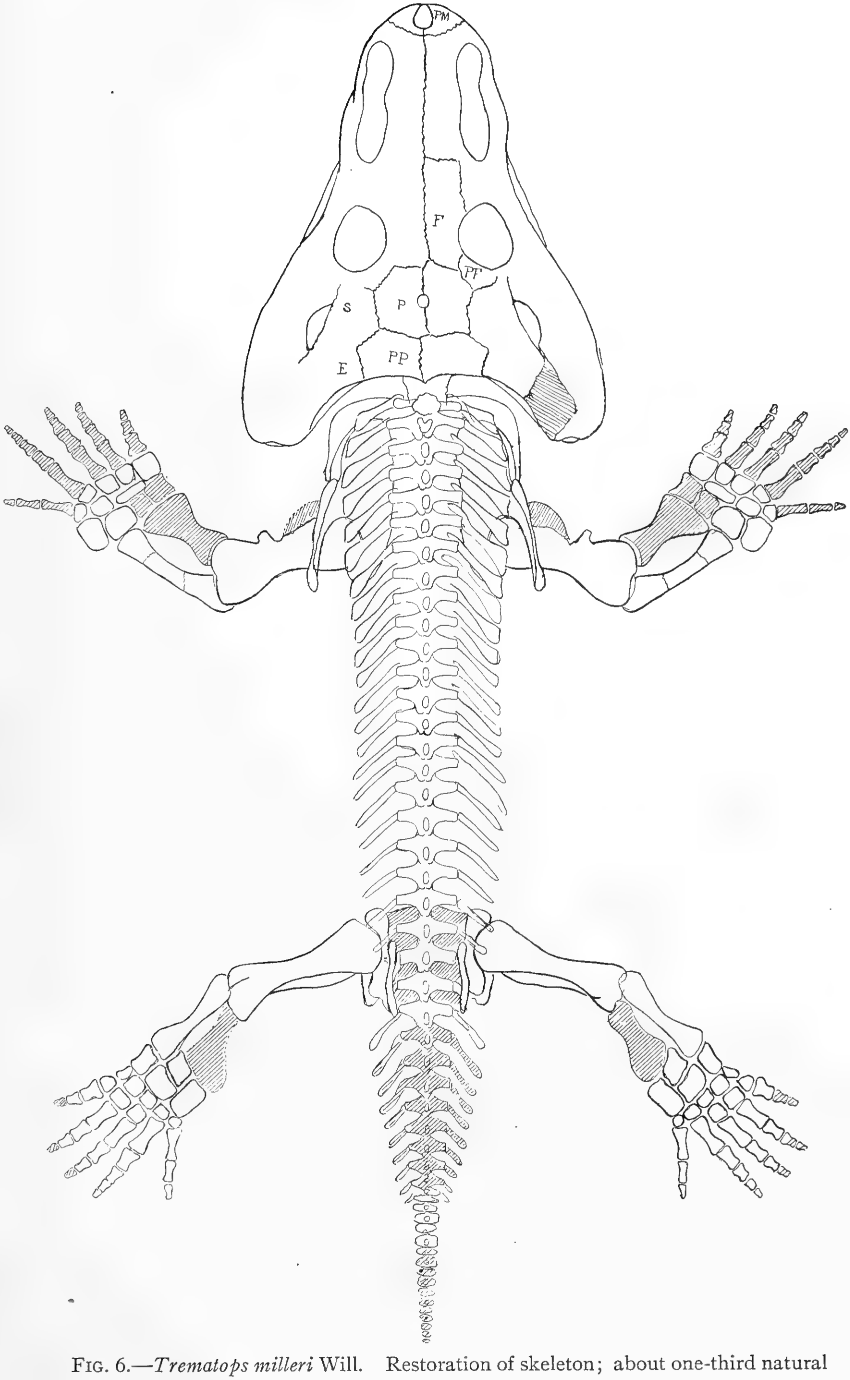

Fig. 6.—*Trematops milleri* Will. Restoration of skeleton; about one-third natural size.

expanded. Its first phalanx is short and expanded, much shorter and smaller than the corresponding phalanx of the third finger. At its distal extremity is preserved the proximal extremity of a very small second phalanx; and there was probably no more present in the living animal. The third metatarsal is much longer than the second, with its proximal extremity more oblique to its long axis. Its distal extremity is quite on a line with the distal extremity of the second metatarsal. The first phalanx is stouter and longer than the first phalanx of the second digit, and a trifle smaller than that of the fourth, its greatest width about equal to two-thirds its length. The second phalanx, preserved entire, is much smaller than the first, and is very short and broad, its width equal to its length; it is but little constricted at its middle. A proximal half or end of a minute third phalanx is also present. It was somewhat pointed in shape, but by no means a claw. The fourth metatarsal is much like the third and of about the same length, its proximal extremity yet more oblique. Its proximal phalanx is a little longer than the first of the third digit, its distal extremity surpassing a little the distal extremity of the third metatarsal. The second phalanx is a little longer but no broader than the second of the third toe. Its third phalanx is about two-thirds the length of the second, but is much narrower distally. The basal of part of the fourth phalanx, a very small bone, is articulated with the third and it is very evident that it was the terminal one, and was very small and in no sense a claw. The fifth toe is slender, and was divaricated in life. In the specimen, while still retaining its articulation with the tarsus, it is turned across the fourth and third metatarsals. Its metatarsal is much narrower, and not more than three-fourths the length of the fourth. Its first phalanx, likewise slender, is about the length of the first phalanx of the second toe, but is much narrower. The second phalanx, much shorter, is narrowed distally, but with a minute terminal knob or expansion. Possibly an ossicle not larger than a pin-head may have articulated here, but probably not.

The actual phalangeal formula of the foot as preserved is, it is seen, 1, 2, 3, 4, 2. It is possible, though not very probable, that the first, second, and fifth digits may have had a minute ossicle at the extremity of each, making the formula, 2, 3, 3, 4, 3. The feet were clawless, the toes ending rather bluntly. The foot as a whole, it is seen, is remark-

able for its broad, short form, and, because of the relatively large size of the tarsus, it must have been very flexible. The absence of true claws, such as occur in some of the Cotylosauria at least, and the Pelycosauria, is what we would expect. The relatively short legs and broad feet were used exclusively in locomotion. The front feet could not have been extended nearly as far forward as the mouth and could have been of no possible use in seizing or holding the animal's prey; and it is quite certain that the creatures did not need claws for locomotion over soft ground.

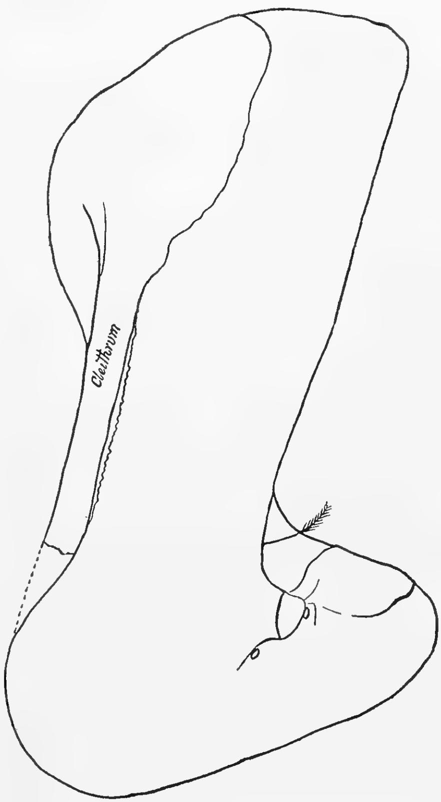

FIG. 7.—Left coraco-scapula of *Eryops latus* Case; about one-third natural size.

In the restoration (Fig. 6) the front toes have been copied from the hind ones, and it is not at all probable that there could have been much difference between them. That there were five fingers is shown conclusively, not only from the carpus, but also from the front foot of *Eryops*, as figured by Cope, a form which, in its skeletal structure, is closely allied to *Trematops*. The radius also is given from the same figure by Cope. The fibula is in part conjectural, as is also the length of the tail. It is possible that the head was set even more closely upon the shoulders.

From the absence of every indication in the matrix of a dermal armor, it is quite probable that the creature had a bare skin; and the absence of claws and its short legs and feet indicate also that the animal lived not on high dry lands, but about the mud shores and in

the water. The entire absence of a neck, which is characteristic of all the lower vertebrates of the Texas Permian, the large, ungainly but flattened head, the short body and tail, and short, rather stout limbs, all must have given to the creature a very bizarre aspect.

The distinction of *Trematops* from other genera of the rhachitomous amphibians described from Texas seems certain. Its relationship with *Eryops* is evident, but, aside from its smaller size and greater slenderness, the structure of the head separates them widely. From *Acheloma*, which I at first thought might be the same, there seem to be marked differences. Cope's description of *Acheloma* leaves certain parts in doubt, parts of much importance in the discrimination of the two genera, especially the size and shape of the vacuities. He describes the premaxillary teeth as five in number and of large size, whereas in *Trematops* they are six in number and are among the smallest of the whole series. He also states that the humerus of *Acheloma*, a very remarkable thing for an amphibian, has an entepicondylar foramen, whereas there is no trace of such in the present form. Dr. Matthew of the American Museum has very kindly compared the type of *Acheloma*, at my request, and confirms these details, and also informs me that the skull is different in shape from the figure sent him of *Trematops*. I have no hesitation, hence, in giving to the present specimen the generic name *Trematops*, chosen in reference to the numerous vacuities of the upper side of the skull.

A further discussion of the habits and relationships of *Trematops* and *Eryops* will be given in a future paper, after other forms have been described, especially a nearly perfect skeleton, with all its bones in natural relations, of a small species of *Pariotichus*, which will furnish the subject for the next paper of this series.

BASE-LEVEL OF EOLIAN EROSION

CHARLES R. KEYES

The recognition of a land-level coinciding very nearly with that of the surface of the sea, but below which stream-corrasion cannot go, is a concept which has had such a potent influence in molding opinion concerning land-sculpturing and its evolution that any exception or modification is yet to receive general approval. That the generalization is not of universal application recent observations afford many proofs. Notwithstanding the fact that Powell's Law of the Base-Level of Erosion[1] had its inception in the arid land, later considerations show that it is really strictly referable only to countries enjoying climatic conditions of normal humidity.

Vast areas of the globe there are where, it must be conceded, the effects of stream-corrasion are necessarily very impotent or practically nil. These are the great arid tracts, or deserts, where the annual rainfall is less than ten inches, nearly all of which sinks into a porous and thirsty soil and never appears in the rôle of stream-water. In such regions, as it has been recently shown,[2] erosion and shaping of the land forms are chiefly accomplished by wind-scour, or deflation. The great vigor with which general eolian erosion may operate, when moisture does not interfere, is indicated by the recent estimates that on the soft rock-belts eolative effects are ten times greater than they would be on the same rocks in a humid land, although on the harder rock-masses the rate is scarcely one-tenth so much.

In the general leveling and lowering of the surface of a country notably elevated and fully exposed to the influences of an arid climate, one of the most remarkable results is that the plain is the characteristic and dominant feature from the very beginning of a geographic cycle; while in a humid climate the plain only becomes notably developed in the very last stage.[3] Eolian erosion in a dry country may thus be

[1] *Expl. Colorado River of the West* (1875), p. 207.

[2] *Bull. Geol. Soc. America*, XIX (1908), 81; also, *Journal of Geology*, XVII (1909), 31.

[3] *Journal of Geography*, VII (1908), 33.

regarded as pre-eminently plains-forming. On this account, manifestly, it is that in the arid regions of our western country there is the vast general plains-surface, a veritable and illimitable sea of earth out of which, isle-like, rise the myriads of lofty desert ranges whose foundations are the harder rock-masses.

In the absence of distinctive stream-action in the desert regions there has appeared no delimiting factor controlling the general lowering of an arid area, comparable to that establishing a base-level of erosion postulated for every humid land. The difficulties arising from this want of a general planation-surface to which all relief features of the desert could be referred are especially noted by Passarge[1] in his masterly treatment of the South African "Inselberglandschaft." Penck[2] also appreciates the same difficulty when he suggests that so long as the ocean be held back from a desert eolian erosion might go on indefinitely below sea-level. In his discussion of the geographic cycle in an arid climate Davis[3] apparently recognizes the force of this desideratum, but refers this most conspicuous plains-characteristic to the results of perfected drainage and general lowering, much as they are accomplished under conditions of humid climate, though at an infinitely slower rate. That there is really a level below which eolian erosion in arid regions cannot go and which for all practical purposes corresponds to the base-level of stream-corrasion in a moist country, seems amply demonstrated by recent observations made in Death Valley and in the Imperial Valley, in California, areas lying below sea-level. The testimony seems fully corroborated in other desert valleys of the region.

Until lately the origin of the larger and most characteristic relief-features of the great desert regions of the globe has remained without adequate or satisfactory explanation. Direct genesis upon the basis of ordinary tectonics, or of normal erosion during former wet-climate periods, or of water-action under present conditions, has always met with unsurmountable obstacles. When recently[4] the physiognomy of our western country was briefly considered from the viewpoint of

[1] *Zeitsch. d. deut. geol. Gesellsch.*, LVI. Bd. (1904), Protokol, p. 191.

[2] *Am. Jour. Sci.* (4), XIX (1905), 165.

[3] *Journal of Geology*, XIII (1905), 382.

[4] *Ibid.*, XVI (1908), 434.

purely eolative origin, the present lofty mountains and the immeasurable intermont plains were regarded simple, differential effects of wind-scour. Extended observations seem conclusively to show that there once existed at a level of about 5,000 feet above the present general plains-surface an old uplifted peneplain. Out of this were sculptured existing highland and lowland, the belts of more resistant rock-masses forming the mountain ranges and the belts of weak rocks the intermont plains. Compared with the usual operations of the geologic processes under normal moist conditions the most noteworthy effects of those under conditions of an arid climate are the prevalency, constancy, and high efficiency of wind-scour action, deflation, or eolation, the very subordinate, local, and sporadic character of water-action, and the remarkable plains-forming tendency which eolian erosion imparts to the landscape.[1]

In the South African deserts Passarge has devoted special attention to the work of the winds. The importance of his great generalization lies in the suggestion that it is possible under conditions of an arid climate for the general planation of vast areas to go on without regard to sea-level. For a long time this author[2] found great difficulty in accounting for the great plains-surfaces by wind action alone, for the reason, as he explains, that the wind has no base-level of erosion and must continue the work of excavation and removal wherever the rock-floor is not resistant. There appears to be, however, a limit even to this desert-leveling and eolian excavation. The ground-water level in a structurally inclosed basin must finally put a stop to wind-action by keeping the surface moist, either giving rise to salinas or forming a basin into which sporadic storm-waters find a long resting-place.[3] This would seem to be the case of the Death and Imperial valleys of California, the basin of Lake Eyre in Australia, the Aral and other basins of western Asia, and many of the great depressions of the Sahara.[4]

The absolute independence of one another of neighboring intermont plains, such as everywhere occur in the American arid regions, is

[1] *Pop. Sci. Mon.*, LXXIV (1909), 23.

[2] *Zeitsch. d. deut. geol. Gesellsch.*, LVI. Bd. (1905), Protokol, p. 108.

[3] *Am. Jour. Sci.* (4), XVI (1903), 377.

[4] *Bull. Geol. Soc. America*, XIX (1908), 91.

perfectly inexplicable on any postulation of normal stream-action. It is, moreover, nowhere more strikingly shown than in the Death Valley district; and it is clearly recognizable throughout the desert country. Nor is this genetic independence of development satisfactorily explained on the basis of tectonics. The profile below, through the Death Valley region, displays these relationships of several adjoining intermont plains.

In neighboring valleys of the dry region the local level below which eolian erosion cannot go seems to be sharply determined by lines where the ground-water surface reaches sky. It is much the same as when in a humid land a barrier to surface drainage fixes for a time the local base-level. Those local geologic structures which

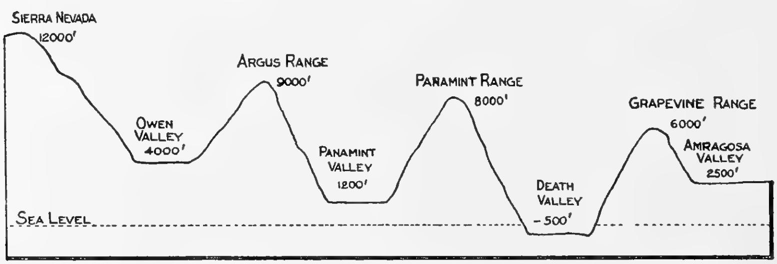

FIG. 1.—Hypsometric Independence of Intermont Valleys of the Arid Region

control ground-water level may be slightly or very different in neighboring intermont areas; but so long as in the one the level of phreatic waters comes to the surface of the ground and in another it does not, the effects of differential deflation will be very marked and plains of the first-mentioned class will remain high above the other, notwithstanding the fact that the two appear to be directly connected so far as their surface drainages are concerned.

Death Valley and the Imperial Valley, before the Salton Sea grew so large through the incursion of the waters of the Colorado River, are good illustrations of this phenomenon. In the case of the first-mentioned of these valleys especially, now about 500 feet below sea-level, it is not at all likely that the salt lake which occupies a portion of its area is so much due to the desiccation of surface waters drained into the depression from all sides as it is to the fact that the valley is excavated by deflation down to a level where it could go no farther on

account of the inflow of phreatic waters. This seems to be also the true explanation of the presence of many of the salinas and playas which are of such frequent occurrence throughout the arid country. The surface waters derived from the violent but sporadic "cloud-bursts" contribute to playa-formation[1] in many cases, but in the majority of instances the ground-waters doubtless have very much the greater influence.

A noteworthy instance is the Sandoval bolson, or Estancia plains, in central New Mexico. This is the highest and driest bolson of the Mexican tableland within the limits of the United States.[2] Its surface is 6,000 feet above the sea. Its center is occupied by a great chain of dry and bitter lakes. In all of its vast area, and during a period of 400 years since the earliest Spanish invasion, only two small springs of potable water were known within its confines. Recently, it was inferred from the general character of the great basin, its geologic structure, and the location of two springs, that ground-water level at certain points must come very near the surface. Proceeding upon this hypothesis several test-wells were put down and the inference found to be correct. At once there was excavated an area of several acres in extent for reservoir purposes. Now there stands a fine large body of soft water, the surface of which comes within a few feet of that of the surrounding plain. Around the lakelet a prosperous town has sprung up.

As the geographic cycle in an arid region goes on and the whole face of the country becomes worn down to the condition of a peneplain there finally must come a time when the general ground-water level nearly coincides with that of the plains-surface and deflation can proceed no farther. This level which is perfectly independent of sea-level can never be very far below it. The base-leveled area in an arid region may thus compare favorably in size and character with any of the peneplains in humid climates. The base-level of eolian erosion under conditions of an arid climate seems as completely controlled and as sharply delimited by definite physical factors as is normal peneplanation.

[1] *Am. Jour. Sci.* (4), XVI (1903), 377.

[2] *Journal of Geology*, XVI (1908), 434.

THE MALASPINA GLACIER REGION OF ALASKA

LAWRENCE MARTIN
Assistant Professor of Geology, University of Wisconsin

The Malaspina Glacier region of Alaska may be of especial interest to geologists at the present time for two reasons. The great earthquakes in Yakutat Bay, just to the east in 1899, involved faulting and changes of level of the land. The eastern portion of the Malaspina Glacier itself, with adjacent valley glaciers, is engaged in one of the greatest ice-advances of modern times, due indirectly to these earthquakes.[1]

Different parts of this region have been described in some detail by the late Professor I. C. Russell, of the University of Michigan, Dr. G. K. Gilbert, of the U. S. Geological Survey and the Harriman Expedition, Professor R. S. Tarr, of Cornell University, and the writer, as well as others listed below.

The model or relief map here described (Fig. 1) includes the Malaspina Glacier, and the adjacent region near Mount St. Elias and Yakutat Bay, about 7,350 square miles in Alaska and Canada, near 60° N. Latitude, and 140° W. Longitude. On this model whose vertical and horizontal scales are the same (1:80,000), about one mile and one-quarter equals one inch. The model is about seven feet by four and two-thirds feet. Its cost of construction was provided by the Geological Department of the University of Wisconsin. It is based upon a brief general view of the whole region by the writer in 1904, upon several months' field-work in the eastern half of the area in 1905, both years in U. S. Geological Survey parties, but chiefly upon maps, photographs, and descriptions by I. C. Russell, and the Alaska Boundary Commissions, as well as the work of Lieutenant Schwatka's *New York Times* Expedition, H. W. Seton-Karr, William Libbey, the Topham Expedition, George Broke, the Canadian Boundary Commission, H. C. Brabazon, the Duke of the Abruzzi,

[1] This region was revisited in 1909 by the National Geographic Society's Alaskan expedition for the study of glaciers under the direction of R. S. Tarr and the writer. Important observations on the additional advance and recession of glaciers were made.

Vittorio Sella, H. C. Bryant, C. E. Hill, the Harriman Expedition, G. K. Gilbert, Henry Gannett, the U. S. Fish Commission, the U. S. Coast and Geodetic Survey, the U. S. Boundary Commission, Fremont Morse, the U. S. Geological Survey, A. G. Maddren, E. Blackwelder, R. S. Tarr, and others.

Over two months were required and about 625 different photographs and a number of maps and charts, including some unpublished

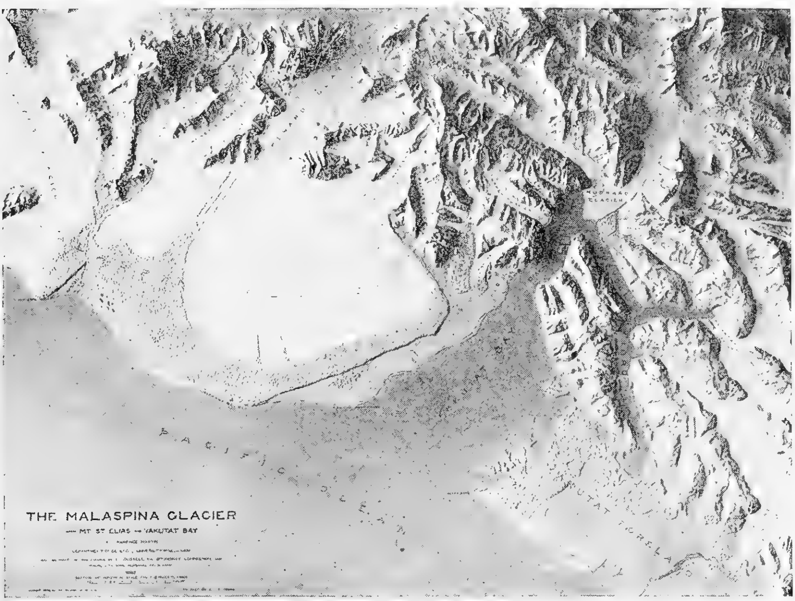

FIG. 1.—The model or relief map of the Malaspina Glacier, with Mt. St. Elias and adjacent mountains, and Yakutat Bay, Alaska.

materials, were used in making the original clay model from which the plaster-papier-maché reproductions are made. An expert mechanician, Mr. E. H. J. Lorenz, has done most of the modeling.

The model shows a portion of the lofty St. Elias range whose snow-fields cover everything above 2,500 to 3,000 feet, where slopes permit. From these snow-fields innumerable glaciers extend down the valleys, in several cases reaching the Pacific Ocean, Disenchantment Bay, or Russell Fiord, and discharging icebergs. One great group of these valley glaciers has united at the foot of the mountains

in a piedmont ice-sheet—the Malaspina Glacier—whose area exceeds 1,500 square miles. Most of this area is clear ice but where parts of the border are stagnant they have been covered by ablation moraine upon parts of which forests have grown. This is the largest glacier in the world outside the Arctic and Antarctic regions.

The east half of the model shows a series of fiords with cirques, hanging valleys, etc., produced by ice-erosion when the glaciers were more extensive, as well as the glacial coastal plain known as the Yakutat Foreland. Marginal lakes, medial, lateral, terminal, and recessional moraines, and outwash plains are shown.

THE VARIATIONS OF GLACIERS. XIV[1]

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The following is a summary of the *Thirteenth Annual Report* of the International Committee on Glaciers.[2]

REPORT ON GLACIERS FOR 1907

The greater number of the glaciers of which we have any information are retreating; the glaciers of the Scandinavian Alps alone are entering a period of advance; this advance, which started some years ago in the Jostedal, became fairly general in 1907.

Swiss Alps.—The retreat is general, but nevertheless it is not so strong as during the preceding years, which is probably due to changes in meteorological conditions. Of the fifty glaciers observed only one, the Glacier de Vorab, in the basin of the Rhine, has shown any marked growth. It advanced 133 meters between 1904 and 1907.[3]

Eastern Alps.—Of the twenty-five glaciers observed in 1906–7, twenty-four are retreating and one is stationary; therefore the slight advance indicated by some glaciers in 1905 has given way to a general retreat.[4]

Italian Alps.—Observations on glaciers on the south side of Mont Blanc, and in the Lombard and the Venetian Alps, show a retreat more or less marked.[5]

French Alps.—Measurements of the amount of snowfall in the neighborhood of Chamonix show that in the winter of 1906–7 the quantity of snow which fell was 20 to 25 per cent. greater than for many years past. This region seems to be passing through a snowy period; nevertheless the glaciers themselves are still retreating, and we shall probably have to wait many years before the heavy snowfall

[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XVL.

[2] *Zeitschrift für Gletscherkunde*, 1909, Vol. III, pp. 161–85.

[3] Report of Professor F. A. Forel and M. E. Muret.

[4] Report of Professor E. Brückner.

[5] Report of Professor O. Marinelli.

becomes effective in an advance of the ice. In the Maurienne also the retreat is general. In the Dauphiné observations have shown very heavy snowfalls and continued retreat of the glaciers.[1]

Pyrenees.—In the Pyrenees the heavy snowfalls covered the small glaciers so completely that satisfactory observations could not be made.[2]

Norway.—A marked change has occurred in the glaciers of Jotunheim; in 1904–5 only six of these were advancing and seventeen were retreating. In 1905–6 seven were advancing and the same number retreating. In 1906–7 fifteen were advancing and only three retreating. In the region of Jostedal and Folgefon the advance, which began earlier, continues to hold its own.[3]

Russia.—Two glaciers in the Caucasus seem to be in retreat; but the Midagrawin and Devdorak, in the Kasbek group, are apparently advancing. The latter glacier is extremely interesting as it has been the cause of many disasters in the Dariel pass. In southern Asia all the glaciers observed are retreating but in the western Pamir the snowfall seems to have increased markedly.[4]

Canada.—The observations of the Messrs. Vaux show that a number of glaciers, namely, the Illecillewaet, the Asulkan, the Victoria, and the Yoho, have all retreated in 1906–7, and some of them very strongly. The Asulkan and the Victoria had been approximately stationary for several years.[5]

Himalaya.—The Geological Survey of India has undertaken to survey the ends of the great Himalayan glaciers for the purpose of determining their variations, so that we may expect definite results before very long.[6]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1908[7]

The Big Timber Glacier in the Crazy Mountains of Montana was visited in 1907 by Messrs. Wolff and Mansfield. The general

[1] Report of M. Ch. Rabot.

[2] *Ibid.*

[3] Report of M. P. A. Oyen.

[4] Report of Colonel J. de Schokalsky.

[5] Report of MM. George and William S. Vaux.

[6] Report of Mr. Douglas W. Freshfield.

[7] A synopsis of this report will appear in the *Fourteenth Annual Report* of the International Committee. The report on the glaciers of the United States for the year 1907 was given in this *Journal*, Vol. XVI, pp. 666–68.

appearance of the glacier indicates that it has been stationary during recent years.[1]

The Arapahoe Glacier, Colorado, does not seem to have changed since 1907, though the winter of 1907–8 was very dry (*Henderson*). The Hallett Glacier has receded slightly (*Mills*).

Professor W. D. Lyman reports that there are large glaciers along the Olympic Mountains in Washington. In particular, the Ho Glacier, on Mt. Olympus, is almost comparable with the glaciers of Mt. Rainier.

Mr. Fremont Morse, of the United States Coast and Geodetic Survey, has kindly sent the following account of the Alsek Glacier, and others near it, at the southeast end of the Brabazon range and northwest of the Fairweather group:

> The Alsek Glacier is divided at the discharging face by a nunatak, and the lower portion discharges into a deep lake in which the largest bergs float around freely. The face showed no perceptible change in location between 1906 and 1908, but this portion of the glacier was considerably more active than it was in 1906, according to the report of my assistant, Mr. L. Netland, who was up the river both seasons. The upper portion of the glacier, above the nunatak, is apparently dying. The ice in it is all dirty, and but few bergs were detached from the face while we were in the vicinity. The face has retreated since 1906, and at the low stage of the river in September there was a gravel bar exposed in front of the ice face.
>
> The next great glacier up the river is on the right bank in the next bend of the river. It is directly connected with the great ice-reservoir from which the nunatak and Hidden glaciers discharge into Russel Fiord, and from which the Yakutat Glacier flows toward the ocean. This glacier seems to be retreating. Its front is now about two and a half miles from the river bank.
>
> At the second canyon of the Alsek the glacier which forms the left bank of the canyon seemed to be advancing slightly on its east side. There the ice was crushing the alder bushes on the lateral moraine in one place that came under my notice. I cannot say whether the front of the glacier had advanced since 1906, but Mr. R. D. Ritchie, assistant to the Canadian representative who was with my party, and who was up the river in 1906, said the glacier was much more active than at the time of his former visit.
>
> I judged from the appearance of the numerous small glaciers in the canyons that the general movement of the ice in the region adjacent to the Alsek was one of retreat.

[1] George Rogers Mansfield, "Glaciation in the Crazy Mountains of Montana," *Bull. Geol. Soc. Am.*, Vol. XIX, pp. 558–67.

The Grand Pacific Glacier, which debouches into the upper end of Glacier Bay on the south and into the valley of the Alsek River on the north, seems to be retreating in its northern portion (*Netland*). This is in conformity with the marked retreat of its southern end, reported for several years.

Dr. L. S. Camicia has been keeping a record since 1901 of the position of the Valdez Glacier, Prince William Sound, Alaska. A stone monument was made on the moraine in front of the glacier and the distance to the ice determined. He found the following variations, measurements having been made in June of each year: 1901–2, a retreat of 39 feet; 1902–4, 165 feet; 1904–5, 138 feet. The next observation was made in October, 1908; as the monument had been destroyed, he estimated its position as well as he could, and found a retreat since the last observation of 244 feet, making a total retreat from 1901–8 of 586 feet. The destruction of the monument seems entirely explained by the advance recorded in the following account kindly sent me by Professor U. S. Grant:

NOTES ON THE GLACIERS OF PRINCE WILLIAM SOUND, ALASKA, 1908

Maps showing the location of these glaciers may be found in Vol. III of the *Harriman Alaska Expedition*, and in *Bulletins 284* (p. 79) and *345* (p. 177) of the U. S. Geological Survey.

Valdez Glacier.—The western part of the front of this glacier was visited about August 1, 1905, and again on July 11, 1908. Some time during this interval the glacier has advanced 250 to 350 feet and built a moraine and then retreated nearly to its former position. On the extreme western edge the ice in 1908 was about 100 feet in advance of its position in 1905.

Shoup Glacier.—This glacier was visited on July 4, 1905, and on July 13, 1908. The front was practically in the same position on each of these dates.

Columbia Glacier.—This glacier was visited by the Harriman Expedition on July 25–27, 1899, and by Grant on July 10, 1905, and July 15, 1908. At the north end of Heather Island photographs show the precise position of the front of the glacier at these three dates. In 1905 the ice front had retreated 160 feet from its position in 1899, and in 1908 it had advanced 112 feet beyond its position in 1905.

Glaciers of Icy Bay.—The maps of this bay, which lies west of the south end of Chenega Island, show it to be about four and a half miles long, with a glacier at its head. A traverse of the shoreline of this bay in 1908 shows it to be about 11 miles in length with a tide-water glacier at its head. On the north side of the bay, 6 miles from its head, is a smaller bay, nearly two miles in length; and at the head of this smaller bay are two tide-water glaciers. The description of Whidbey, who

was attached to Vancouver's exploratory expedition of 1794, states that this bay was four and a half miles deep and was terminated by a perpendicular cliff of ice. This would seem to indicate a retreat of ice in the axis of Icy Bay of some six and a half miles from 1794 to 1908.

Glaciers of Port Nell Juan.—There are three tide-water glaciers in this bay, all showing retreat in recent years. The largest of these glaciers is in the third (from the entrance) of the southerly arms of Port Nell Juan. Near the western side of the end of this glacier there is a granite knob, rising some 175 feet above tide, on which is a small moraine marking an advance of the ice into a straggling forest. This advance was probably about 20 years ago, since which there has been a retreat of the ice for 500 feet.[1]

Barry Glacier.—In 1905 this glacier was found to have retreated markedly since 1899. It was visited again in 1908 and its front was found to have retreated on the east side about a fourth of a mile, and more than this on the west side, since 1905.

Bainbridge Glacier.—Within the last few years this glacier has retreated to a small extent as shown by a bare, treeless zone on the south side of the front, and by a small moraine on the north side of the front. This moraine on August 3, 1908, was 30 to 60 feet in front of the end of the glacier, and the moraine in part lies against a forest some of whose trees were overturned by the ice.

The Matamaka Glacier, the source of the river of the same name, which flows into the head of Cook Inlet, was apparently retreating in 1905. The glacier was from three to five miles at its end (*Griffith*).

[1] There was a slight advance of Muir Glacier between 1890 and 1892.

Reviews

The Guadalupian Fauna. By George H. Girty. Professional Paper 58, U. S. Geological Survey. Pp. 651, 31 plates. 1909.[1]

The appearance of this work, which, according to Dr. Girty, has been in the form of page-proof nearly a year and a half, marks an epoch in the production of fine monographic reports on the upper Paleozoic faunas of America. The subject-matter is no less interesting and important than the quality of the workmanship on the book. It brings to light the most unique and one of the most important faunas known from the American Anthracolitic rocks, and one which must be reckoned with in any broad correlation of horizons above the Mississippian. It represents an immense amount of careful work and painstaking discrimination on the part of the author.

This fauna was first discovered by G. G. Shumard in 1858, and was described by his brother, B. F. Shumard, in 1859. Since that time it has remained unnoticed until the appearance of the present elaborate report, save a couple of preliminary papers by Dr. Girty. All told there are 326 species and varieties. Of these, over 180 forms are defined and illustrated as new, over a hundred undesignated; the remainder are previously described species.

In the introduction the stratigraphy is passed rather briefly; 51 pages are devoted to it and the correlation, the remainder being given to the systematic paleontology.

The stratigraphic relationships of these Permian beds are peculiar and interesting. They are brought to the surface by a westward-facing fault-scarp as it dies out into a fold to the south. Other mountains occur to the west and northwest with older faunas, and only in this one locality is the nearly full section of the Guadalupian rocks shown. The Capitan limestone (white Permian limestone of Shumard) is 1,700 or 1,800 feet in thickness. Below this is the Delaware Mountain formation composed of dark limestones and sandstones with a black limestone 200+ feet thick

[1] The cover and title-page bear the date 1908. However the book was not distributed until about February, 1909. Ordinarily this close discrimination of dates would be unnecessary, but since something over 180 new species, nine or ten new genera, and three new families of a rather cosmopolitan fauna are named and defined it is important that the date on the title-page should be correct.

beneath it, giving, all told, some 2,500 feet to this formation and a total of about 4,000 feet to the whole Guadalupian section as shown at the southern extremity of the mountains. The stratigraphy was largely worked out by Richardson.[1] To the east, on the dipslope of the mountain, the Capitan limestone is wanting. An erosional unconformity is found on the Delaware Mountain formation upon which rests the Castile gypsum. The exposures of the region show 50 or 60 feet of it and a well at Rustler spring penetrated it to a depth of 300 feet. Upon this gypsum lies the Rustler formation consisting of magnesian limestones and sandstone with an average thickness of about 200 feet. To the east, and upon this, lie the Red beds. Richardson's interpretation of the stratigraphic succession is as follows:

> The Castile gypsum along its western outcrop lies on little knolls and valleys of the underlying Delaware Mountain formation, indicating an erosional unconformity. Another evidence of unconformity at the base of the gypsum consists in the absence of the Capitan limestone. It appears that either the gypsum was deposited at or near the top of the Delaware Mountain formation as a lens which did not extend westward to intervene between the Delaware Mountain formation and the Capitan limestone in the Guadalupian Mountains, or that erosion had removed the former southwestward extension of the limestone (the thickness of which is unknown) before the deposition of the gypsum. The former position necessitates the correlation of the Rustler formation, which overlies the gypsum, with the upper part of the Delaware Mountain formation or the Capitan limestone. But there is little to support this interpretation, and it is tentatively assumed that the Castile gypsum and the Rustler formation were formed after the deposition and erosion of a part of the Capitan limestone.[2]

The Red beds approach the Guadalupes closely from the north, and Tarr states that a thousand feet or more of sediments come in on top of the Capitan limestone to the north in New Mexico. Up to the present time the Triassic has not been reported from southern Texas and southern New Mexico, Lee's researches along the Rio Grande in New Mexico and[3] the explorations of the Texas survey having failed, so far, to reveal it. So it would not be at all impossible that the Rustler formation pushes up the dipslope and over the Capitan limestone farther north, and that both lie beneath the upper Red beds. However, it is not certain that this happens, and Dr. Girty's interpretation of the faunas seems to be that such is not the case. Nevertheless the fact that the unconformity exists, that the Capitan limestone is unknown beneath the unconformity lying upon its natural dipslope, and

[1] *Bull. 9*, Univ. Tex. Min. Surv., 1904.

[2] *Op. cit.*, pp. 43, 44.

[3] *Jour. Geol.*, XV, pp. 52–58, 1907.

Tarr's statement that a thousand feet or so of rocks come in over the white limestone (Capitan) a little farther north in New Mexico, would seem to be indicative of the stratigraphic position of the Guadalupe beds. However, the age of the uppermost beds has not been ascertained. Even though they were Triassic it would seem to leave the Guadalupe beds below the Permo-Triassic unconformity which is known to exist in the Texas Panhandle, northern New Mexico, and Colorado. This would leave a strong possibility of the Capitan limestone being no younger than the Whitehorse beds, or the Quartermaster beds[1] at best.

However, Dr. Girty, who has been over the south end of the Guadalupes passes Tarr's statement —that "the total section exposed in the Guadalupes, approximately stated, cannot be less than 4,000 feet, including the New Mexico series, which exist above the white limestone"—with the remark:

> I do not know what rocks are intended by this indefinite statement. The Capitan limestone is not known in Texas, so far as I am aware, save in the Guadalupe Mountains and the foothills adjacent, where no overlying series is exposed. It must of necessity extend northward into New Mexico, unless faulted out, but all our faunas from New Mexico, so far as I have examined them, show an altogether different facies, one more suggestive of beds which there is every reason to believe lie below the Guadalupian.

The fauna consists of 326 forms: Protozoa, 9; Sponges, 24; Coelenterates, 10; Echinoderms, 7; Vermes, 1; Bryozoa, 44; Brachiopods, 128; Pelecypods, 45; Scaphopods, 1; Amphineura, 1; Gastropods, 42; Cephalopods, 9; Crustaceans, 5. "Aside from the species which Shumard had described, most of the Guadalupian forms appeared to be new." The characteristics of the various classes are briefly mentioned, followed by lists from the various localities and horizons.

The principles which have guided the author in making his determinations are stated as follows:

> It has been said no less truly than often that it is easier to combine two species that have been injudiciously discriminated than to disengage two species that have been injudiciously combined, and it is also true that loose discriminations and loose identifications lead to loose correlations. I have felt under obligations to the workers in this field to leave a species whose relationship I was unable to determine as unentangled as possible, and to establish the nomenclature on a reasonable and permanent basis. Consequently, in doubtful cases I have leaned consciously to the side of species-making, nor would I feel deeply concerned should it prove on just evidence not now accessible to me that some of my names are synonyms.

[1] See *Kans. Univ. Sci. Bull.*, IV, No. 3, pp. 115–71, 1907.

In accordance with these principles his specific discriminations are very close. This is a thing to be desired provided it is taken into account that mere difference of species is of much less significance than when broader definitions are used. The closer the specific discriminations are drawn the closer the relationship of distinct species may be. This fact should be taken duly into account in making wide correlations of faunas.

In working out these relationships and correlations eight pages are devoted to the enumeration and citation of foreign literature on the Anthracolitic faunas of the world, with brief sentences as to their relationships to the fauna described. About ten pages are devoted to the discussion of the relationships of the Guadalupian, Kansan, and Russian faunas.

With regard to the foreign faunas he states:

In all these faunas there is none, I regret to say, with which the Guadalupian can really be considered to be closely allied. The nearest are probably the Salt Range and Himalaya, in India, and the Fusulina limestone of Palermo, in Sicily; but in this judgment, in the case of the Indian faunas especially, I may have been too strongly influenced by the occurrence of those two singular brachiopod types, *Richtofenia* and *Leptodus*. The fact is perhaps without special significance, but it may be noted that the occurrences of this faunal facies, or at least the occurrences of these genera, in the three instances mentioned, occupy closely corresponding positions with regard to the earth's equator, and may indicate a zonal development in the late Carboniferous.

Again:

The resemblances shown by the Guadalupian fauna to even the most similar of those brought into comparison are sporadic and almost immediately offset by differences as great.

It may be that the author has discounted relationships because the species, minutely discriminated, are not identical with those in these very widely separated countries.

Tables, such as those used by Diener in his work on the Himalayan faunas, indicating the distribution of identical and allied species throughout the world and which are so very helpful in epitomizing a work like this, are wanting. The discussion of the relationships of the faunal units is given under the head of the family in which the species or genus occurs, in the systematic part of the work. To collect these scattered discussions and tabulate them so that any general deductions could be drawn from them by the reader is beyond the scope of a review of this kind.

In the discussion of the Kansas and Russian Anthracolitic faunas Dr. Girty states:

Regarding the correlation of the Kansas "Permian" with the Russian Permian I have not seen any very explicit or satisfactory evidence. The question, it appears

to me, should be considered both in the relation of the Kansas fauna and the Permian fauna as individual and detached entities; in the entire faunal sequence of Kansas to the sequence of the Russian faunas; and, finally, in relation to the collateral evidence which the faunas of other sections bring to the discussion.

The chief arguments which Mr. Prosser has advanced for the correlation seem to be these: The great development of *Fusulina* in the Russian section just below the Permian, paralleled by the development of the same group precedent to the "Permian" of the Kansas section; the development of *Bakewellia* in the Kansas "Permian" and the typical Permian of Russia; and the development in the same beds of the *Pseudomonotis* group of shells. As to *Pseudomonotis*, the genus was introduced in the Kansas section considerably before the "Permian." The abundance with which it occurs at about the horizon of the Kansas "Permian" appears to me a subordinate matter. Again, after critically examining the best specimens of *Bakewellia* which could be obtained, I have been brought to entertain serious doubts as to their generic identity with the *Bakewellias* of the English Permian as represented in King's monograph. The dentition appears to be different and they seem to lack the characteristic series of ligamentary pits.

The statement of the early appearance of *Pseudomonotis* in the Kansas rocks is true, although it had not been noted when Prosser's statement was made in 1895, but it is very remarkable that this fact should be used as an argument against the youth of the higher beds in which it is abundant and characteristic. The same could be said of other Kansas fossils, but I regard it as an indication of the relative youth of the Kansas deposits, rather than their antiquity. Some of the species referred to *Bakewellia* probably belong to Jakowlew's genus *Cyrtodontarca* from the Permo-Carboniferous of southeastern Russia, while the others may be closely related to them. The Coal Measures rocks of the world, so far as I am aware, nowhere exhibit the faunal assemblage of these shells and the associated pelecypods found in these strata in Kansas.

As to the occurrence of the Fusulinas referred to above, it would seem to be the strongest possible evidence in favor of the homotaxy of the deposits. The differences pointed out by Dr. Girty—mentioned later—between the Kansas species and those of Europe are, perhaps, not so important as he supposes. In fact the Fusulinas from many of the Kansas horizons, were sent by St. John to Moeller who carefully studied them and referred them to European species. After studying the Fusulinas from practically all the horizons above the Oread limestone in Kansas the late Dr. Schellwien's letters are decidedly positive, not to say emphatic, on these points and opposed to Dr. Girty's views.

It might also be pointed out that just below the Artinsk a zone in the Russian section is characterized by the profusion of *Schwagerinas* occurring associated

with Fusulinas. Now *Schwagerina* has never been reported from the Mississippi Valley, while I have recently offered reason for believing that the Fusulinas of the Kansas section, if they do not belong to a different genus, at least show important differences from the typical Fusulinas. These facts seem to destroy Mr. Prosser's argument so far as this item of evidence is concerned. At the same time these very forms furnish more staple evidence looking somewhat in the same direction.

In his discussion of the Kansas "Permian" Dr. Girty, as he states in another place in the discussion, refers only to the Chase stage, that is, the strata between the Wreford limestone and the Winfield limestone inclusive and the Marion formation.[1] The burden of Dr. Girty's argument, quoted above, and more especially stated by him in other places in the book, is that the Chase stage seems to be of Gschelian age,[2] although he is undecided about it and commits himself to no positive correlation. Since he wrote the statements last quoted, typical Schwagerinas have been found in the Kansas rocks. They were found, not up in the rocks of the Chase stage, but in the Neva limestone a hundred and fifty feet below its base. It is associated with Fusulina of the *longissima* type on the one hand, and, more or less closely, with a micro-foraminiferal fauna of Permo-Carboniferous character on the other. Spandel described, from the same locality and probably from the same stratum, a micro-foraminiferal fauna, mentioned by Dr. Girty, partly of distinctly Coal Measures types and partly of distinctly Permian types.

Following this Dr. Girty points out a long list of Permian fossils of Eurasia which are wanting in the Kansas section, which is interpreted as evidence against the Permian age of the Kansas rocks. Among these are Strophalosia, five species of Productus, etc. Strophalosia is not uncommon in several beds near the base of the Chase stage, 114 specimens of a species of it having been taken from a single layer in a small exposure of the Garrison formation, and altogether about 250 specimens of it have been noted. They are not of the Zechstein type, however, but are of the type, probably, of *S. parva* King, of the English Permian.

It would seem that the general physical conditions prevailing throughout

[1] Almost without exception the Kansas writers have used the term "Permian" in the sense of including the Artinsk, as have almost all paleontologists. Dr. Girty is mistaken in his assumptions to the contrary.

[2] In the use he makes of the term Gschelian he includes the Schwagerina horizon which is wanting in the type locality of the Gschelian and comes in above it in the Ural-Timen region. It is not so included by many European writers. He here takes the opposite stand from what he assumes in refusing to class the Artinskian with the Permian.

the world at the beginning of and during, Permian time must be taken into account in making broad correlations of Carboniferous and Permian faunas. The significance of the evolution of a provincial fauna in a great epicontinental sea, covering two or three hundred thousand square miles, with inadequate and perhaps only intermittent connection with the open sea of the continental shelves in America, should be as great as the evolution of a fauna in the Urallian region. This significance is increased when it is taken into consideration that both developed during the time when the water was being drawn from the shelves of both continents and the areas of the inland seas were being greatly reduced.

In this light the parallelism in the nature of the deposits of the two regions, accompanied by a like parallelism of faunal changes, is of fundamental importance, and deserves a larger consideration than Dr. Girty has given it. For instance, the introduction of new faunal elements, the sudden and nearly complete disappearance of the Fusulina, and the occurrence of Schwagerina bear the same relations to the early gypsum deposits and the development of the Red beds, in the Kansas section, as they do in the eastern part of European Russia. If I read the stratigraphic account of the Guadalupes aright, it seems that the general considerations of the later Permian apply to them likewise. The unconformity, if such it be, carrying away the Capitan limestone from the flanks of the mountain of which it forms the top, and over the unconformity the deposition of the Castile gypsum, Rustler formation, and Red beds strongly suggest that the Guadalupe region was similarly affected with the region to the northward so far as a general Permian emergence is concerned. In this light the Guadalupian faunas must be largely contemporaneous with the Permian faunas of America and Eurasia. In the eyes of the reviewer, judging from figures and descriptions only, there is where their faunal relationships would also place them.

The point is made that the faunas are so different that, if they are contemporaneous with those of the Mississippi valley—of which Dr. Girty seems to be doubtful—they could not both be covered by a single general term [like Permian ?] for their designation. That they are quite distinct from anything yet brought to light on the continent will be granted at once by anyone familiar with the subject. The one is a cosmopolitan, open-sea, coastal-shelf fauna while the other is a more isolated epicontinental sea fauna rather thoroughly separated from its neighbor on the south and perhaps belonging to a different climatic zone. Should they prove to be equivalent in time I see no reason why they might not be covered by a single term of ordinal rank, their local geologic designations being sufficient to differentiate them.

That it was impossible for the Guadalupian and Mississippi valley clear-

water faunas to intermingle to a considerable extent after the time represented approximately by the Topeka limestone, unless by a circuitous route, no one acquainted with the geology of the intervening region would hesitate to state.

It is very difficult to determine what Dr. Girty's conclusion as to the relative age of the Guadalupian, Russian, and Kansan deposits is. It is very evident, however, from the bulk of his reasoning, that he considers both of the former younger than the Kansan deposits. It is also to be remembered that the book was written, and perhaps in type, before the later Kansas studies were published. He was also handicapped by the fact that he was without a personal field knowledge of the Kansas Permian deposits, and for this reason fails fully to appreciate the changed aspect of the fauna, noted by all the paleontologists who have studied the region, from Meek to Prosser.

J. W. BEEDE

A Key for the Determination of Rock-forming Minerals in Thin Sections. BY ALBERT JOHANNSEN, PH.D. New York: John Wiley & Sons.

This work contains about 540 pages of text and tables conveniently arranged for laboratory use. It is much more than a key, for all of the most useful optical methods are described in a concise manner, which will be appreciated by anyone who is engaged in the microscopic study of rock sections. It will be especially helpful to the geologist who uses petrology as an aid to the study of problems of general or economic geology and who finds it necessary to review his optics each year at the beginning of the period of office work.

The arrangement of the tables is original and excellent. The first page of the table for each group is a diagram showing the birefringence, double refraction, and optical character of each numeral of the group. The color plate or table of birefringences in the back of the book is large enough to be useful and not too large to be handled conveniently. There is hardly a diagram or a table which is used by petrographers in everyday practice which is not given in the *Key* and the whole arrangement is designed to gain accuracy and save time.

W. H. E.

Synopsis of Mineral Characters. BY RALPH W. RICHARDS. New York: John Wiley & Sons.

In this useful work of 100 pages the most important minerals are arranged alphabetically and their chief chemical and physical character-

istics are briefly stated. Emphasis is laid on the form, habit, cleavage hardness, and other physical qualities and such chemical tests as may be made by very simple methods. Reference is made to the pages upon which the minerals are described in Dana's, More's, and Parsons' mineralogies. The work is a convenient aid in the mineralogical laboratory, and is very useful and sufficiently comprehensive for the prospector and for the mining engineer who may not wish to carry a larger volume.

W. H. E.

Geological Survey of New Jersey. Annual Report, 1907. By H. B. Kümmel, State Geologist. 192 pp., 49 pls., 6 maps. Trenton, N. J., 1908.

This report contains the following papers: "Inland Waterway from Cape May to Bay Head," by H. B. Kümmel and C. C. Vermeule; "Improvement of Manasquan Inlet," by L. M. Haupt; "Mineral Industry with Statistics," by H. B. Kümmel; and "Petrography of the Newark Igneous Rocks of New Jersey," by J. V. Lewis. The last article constitutes the major portion of the bulletin. C. J. H.

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He won't be happy
till he gets it!
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JOURNAL OF GEOLOGY

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DIASTROPHISM AS THE ULTIMATE BASIS OF CORRELATION

THOMAS CHROWDER CHAMBERLIN
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XVI

There are many and diverse views relative to the nature and the causes of diastrophic movements. To keep as largely as may be on common ground, most of these divergencies of view may be set aside as immaterial to our present purpose. We may all agree that the fundamental factors of the case are a lithosphere with a deformable surface, a liquid, covering part of this surface and determining erosion and sedimentation, and a gaseous envelope. We may easily agree that the outer part of the lithosphere is solid and has a sufficient measure of rigidity to maintain the surface inequalities. I do not see that we need to agree as to the causes of deformation. In some sense, I do not see that we need even to agree as to just what the absolute movements were, i. e., I do not see that it is material for us here to know whether the deformative movements were shrinkages, or expansions, or lateral shifts, provided we agree as to the general nature of their effects on the agencies at work on the surface of the lithosphere. We do not need to entertain the same conception of the nature of the earth's interior, if we are at one as to the working conditions which have prevailed on its surface.

No doubt we can easily agree on the present great working factors: (1) abysmal basins occupying about two-thirds of the earth's surface, bordered by terrace faces rising at angles of 2° to 5° for say 12,000

feet to a quite definite terrace-angle about 100 fathoms below the sea-level; (2) continental platforms whose upper faces slope gently up from this angle to the coast-line and thence ascend into the various reliefs of the land. If we thus agree that the upper face of the continental platform is bounded by the edge of the continental shelf, and that this edge is equally the boundary of the abysmal basins, whether the waters overlap the edge or not, we may also agree that the edge of the oceanic waters, whether they agree with the edge of the abysmal basins or not, form the chief line of demarkation between the great erosions and the great depositions the world over. It is not the only line of such demarkation, to be sure, for degradation gives place to aggradation at many other local horizons, but in this discussion let us agree to deal only with factors of the larger order and to neglect incidentals; let us deal with body deformation, rather than local or provincial warpings. We all recognize further that the sea-level is not only a dividing plane between two great divisions of physical agencies, but between two great biological divisions.

To this list of agreements, there are two other propositions which we cannot add quite so unhesitatingly, because we need to weigh them well, and if we cannot all agree respecting them, we must agree to differ, for they are fundamental to the further discussion. These relate to the effects of body deformation on the relations of land and sea.

If deformation were confined to the abysmal bottoms and were compensatory, no effect would be felt on the relations of land and sea. If deformation were confined wholly to the interior of the continents, it would be similarly ineffectual. Deformations so limited are, however, likely to be only provincial, and fall outside our discussion.

There remain two conceptions of general or body deformation between which choice must be made. In the one, the deformations are supposed to be indifferent to their predecessors, and to disregard the configurations produced by previous deformations. Their successive effects upon continental outlines and basin capacities are thus heterogeneous and the combined results irregular and uncertain. It is not clear to me how they can be made a very trustworthy basis of systematic correlation. The submergent phase of one continent

or fraction of a continent may, in this case, be contemporaneous with the emergent phase of another continent or fraction of a continent, and the progress of events on one continent is as likely to be contrasted with those of another continent as to fall in with them co-ordinately.

According to the other view, deformations are inheritances, one of which follows another in due dynamical kinship. The succession is therefore homogeneous and the results co-ordinate. If, for example, the first depression of the abysmal basins was due to the superior specific gravity of the basin-bottoms, this specific gravity remained and participated in the next deformation. If the continental masses, at the outset of continental formation, were relatively low in specific gravity, this low specific gravity was handed down to later periods and helped to renew deformation of the same phases in the same regions. Under this view, ocean basins and continental elevations tended toward self-perpetuation. It is not assumed that this prevented shell crumplings, provincial warpings, or block movements of diverse phases within the continental or the abysmal areas, for these might obviously be necessary effects of the general deformative movements, or at least inevitable incidents connected with the dynamics lying back of them.

A choice between these two conceptions is imperative to this discussion, as they lie at the parting of the ways in the interpretation of the larger events of geologic history. I accept the second view with much confidence. It should be more fully qualified respecting the incidental accompaniments just mentioned, but time does not permit.

According to this view, each great diastrophic movement tended toward the rejuvenation of the continents and toward the firmer establishment of the great basins. The distinction between continent and basin must not, however, be interpreted on the superficial ground of the water-line, for the water-line merely shows that the basin is over-full, just full, or under-full, as the case may be. The average water-line undoubtedly helps to give a definite terrace border to the abysmal basin, but the water-line freely abandons this and often is far from coinciding with it.

The base-leveling processes have shown that they are able to lower the continents approximately to the sea-level in a fraction of

geologic time. The continents would therefore have long since disappeared, if they had not been rejuvenated by renewed relative elevation or the withdrawal of the sea. I am able to find no evidence of lost continents. There are submerged margins, and matter has been carried continent-ward from denuded borders. There are some submerged dependencies and inter-continental connections. There are also some rather deeply submerged ridges that probably connected the present continents at remote stages in their history. In the earlier eras, when the differentiation of platforms and basins was less advanced, ridges which have since been submerged are perhaps recognizable. In the interpretation of the earlier periods, these should probably be restored as continental connections. In the earliest known ages, these may have been rather numerous and their combined area considerable, but these seem to me to be only qualifying features which, by the natural place in evolution which they fill, support, rather than weaken, the general conception of a systematic succession of deformations in which the offspring of each is the parent of the next, and in which both continents and ocean basins were progressively segregated and unified.

I trust that many of you will agree that, in general, the relatively upward movements of diastrophism have been located continuously in the continents, and the broad downward movements continuously in the ocean basins, and that, setting aside incidental features, the dominant effect of the successive diastrophic movements has been to restore the capacity of the ocean basins and to rejuvenate the continents. This conclusion seems to me to be strongly supported by the general course of geologic history, wherein sea-transgressions and sea-withdrawals have constituted master features. Perhaps our firmest ground for this conviction is found in the present relations of the continents and the sea basins. If heterogeneity had dominated continental action in the great Tertiary diastrophisms, the results should stand clearly forth today. Some continents should show recent general emergence, while others should show simultaneous general submergence. The dominant processes today should be those of depressional progress, on the one hand, and those of ascensional progress, on the other. As a matter of fact, all the continents are strikingly alike in their general physiographic attitude toward

the sea. They are all surrounded by a border-belt, overflowed by the sea to the nearly uniform depth of 100 fathoms. These submerged tracts are all crossed by channels, implying a recent emergent state. None of the continents is covered widely by recent marine deposits, and yet all show some measure of these. Wide recent transgressions in one part do not stand in contrast with great elevations in another. Even beyond what theory might lead us to expect, when we duly recognize the warpings incidental to all adjustments, the recent relations of the continents to the seas conform to one type. The 10,000,000 square miles of continental margin, now submerged, is distributed around the borders of all the continents with a fair degree of equability. May we not, therefore, agree that in the world-wide phases of diastrophic movements, the basins have been additionally depressed and the continents repeatedly rejuvenated.

It is important that we should agree, or agree to disagree, on one further point. Have diastrophic movements been in progress constantly, or at intervals only, with quiescent periods between? Are they perpetual or periodic? The latter view prevails, I think, among American geologists. This view has acquired especial claims since base-leveling has come to play so large a part in our science, for it is clear that the doctrine of base-leveling is specifically inconsistent with the doctrine of perpetual deformation, for the very conditions prerequisite to the accomplishment of base-leveling involve a high degree of stability through a long period. The great base-levelings, and the great sea-transgressions, which I think are little more than alternative expressions for the same thing, have, as their fundamental assumption, a sufficient stability of the surface to permit base-leveling to accomplish its ends. Shall we not therefore agree that there has been periodicity in the world-warping deformations? Let this not be held with such exclusiveness that we fail to recognize duly the effects of the adjustment of minor stresses, at other times. These may be preliminary or after-effects of the larger movements, or they may be due to local stresses more or less independent of the general body-stresses. These quite certainly have been present, and have produced intercurrent departures from the strict tenor of the great systematic movements.

If there is need for additional argument on periodicity, it may be

found in theoretical considerations, but these we have tried to avoid in the main. Whatever we may regard as the fundamental agencies that give rise to those stresses in the earth which are precedent to deformations, we may easily all agree that the earth opposes some resistance to deformation. There is certainly some rigidity in the body of the earth. According to the fundamental laws of rigidity, the deforming stresses must reach a certain magnitude before a movement can start. Now, if we recall that every such deformative movement, affecting a free surface, in its very nature, throws the resisting crust into an attitude of relative weakness, it follows that, with such progressive easing, the movement will go on until the stress is accommodated and a state of equilibrium essentially restored, after which another period of accumulation is prerequisite to another movement.

If we are agreed on the periodicity of great deformations, it clearly follows that in a quiescent state the base-leveling of the land means contemporaneous filling of the sea basins by transferred matter, and hence a slowly advancing sea-edge which is thus brought into active function as a base-leveling agent. This water movement is essentially contemporaneous the world over, and is thus a basis for correlation. *The base-leveling process implies a homologous series of deposits the world over.* At first these represent the conditions immediately following continental rejuvenation. Later they are succeeded by the deposits representing the modified conditions to which the first stage gives rise, and so on through the series up to the climacteric ones when base-leveling has reached its greatest development. After this a declining series follows. The deposits of the more advanced stages of base-leveling are, as now well recognized by most American geologists, markedly different in physical constitution and physiographic aspect from those of the earliest stages of continental rejuvenation. The criteria for discrimination between these earlier and the later members of the series are indeed of the collective rather than the individual type; they have character as distinctive assemblages of criteria rather than as single or isolated criteria, but they are perhaps all the safer for this composite character.

Correlation by base-levels is one of the triumphs of American geology; correlation by its complement, transgressive deposits on a

base-level, may easily be added, and perhaps on quite as firm or even firmer physical grounds. If we add the biological element the case is immeasurably strengthened, for correlation by cosmopolitan faunas, the very best of faunas for the purpose, is added to the physical correlation. Migration at the climax of base-leveling and sea-transgression is freer and more prompt than at other times. Correlation to the foot, as by an unconformity, may not be practicable, but the precision of correlation by unconformities has more apparent than real value, for the different parts of the same unconformity vary much in time. All distant correlations involve some measure of inexactness, and the more frankly it is made obvious, the less its liability to mislead.

Correlation by general diastrophic movements takes cognizance of four stages: (1) the stages of climacteric base-leveling and sea-transgression, (2) the stages of retreat which are the first stages of diastrophic movement after the quiescent period, (3) the stages of climacteric diastrophism and of greatest sea-retreat, and (4) the stages of early quiescence, progressive degradation, and sea-advance.

(1) The characteristics of the climacteric stage of base-leveling and sea-transgression need little further characterization here, for the function of base-levels is known to all American geologists and the function of great sea-transgression to every stratigrapher and paleontologist. We have in base-leveling conjoined with sea-transgression, just that combination of agencies which is competent to develop the broad epicontinental seas of nearly uniform depth requisite for an expansional evolution of shallow-water life. At the same time, it furnishes broad pathways around and across the continental surfaces for wide migrations and the comminglings that lead to cosmopolitan faunas of the shallow-water type.

(2) The stages of initial diastrophism and sea-retreat find their criteria in the deposits that spring from an increased erosion of the deep soil-mantles accumulated in the base-level period, in the effects of increasing turbidity, in the lessening areas suitable for the shallow-water life, and in the limitation of migration.

(3) The climacteric stages of diastrophism are marked by the stress of restrictional evolution among the shallow-water species; by increased clastic deposition in land basins, on low slopes, and on sea

borders, by great land extension, but often, perhaps dominantly, by diversity of land surface and by liability to climatic severities and diversification. Areally, land life is favored, but it is hampered by the climatic and topographic diversities, and these may prove graver obstacles to migration and intermingling than even the tongues of sea that previously traversed the land surface. Correlation by glaciation in these stages is likely to prove a valuable adjunct, but we must first test our criterion, for we are not as yet quite sure that contemporaneity of glaciation is inferred on reliable grounds. The shallow-water life of the diastrophic stages is driven into narrow border tracts and into local embayments, and is thus forced into special adaptations and into narrowly provincial aspects.

(4) The early stages of quiescence and of base-leveling, with advancing seas, are peculiarly fruitful in biological criteria, for they are marked by re-expansions of the narrowly provincial shallow-water faunas of the previous stages. The progressive development of these provincial faunas and their successive unions with the faunas of neighboring provinces, as these come to coalesce by means of the progressive sea-advances, form one of the most fascinating chapters in life evolution, and give some of the most delicate of criteria for correlation.

This rough outline is quite too meager duly to set forth the criteria of correlation connected with the stages of general diastrophism. It rather suggests them than sets them forth.

It remains to consider the precedence among themselves of the three factors, diastrophism, deposition, and life development.

We are accustomed to look to the life record as our chief means of correlation. Its very high utility is quite beyond discussion. Thoughtful students, however, recognize that the paleontological record is based, in an essential way, on stratigraphy and that it is corrected and authenticated by the precise place the life is found to occupy in the stratigraphical succession. Stratigraphy and paleontology thus go hand in hand, each sanctioning the other. *Diastrophism lies back of both and furnishes the conditions on which they depend.* The relationship is not reciprocal in any radical sense. The life does not, in any appreciable way, affect diastrophism. Deposition has been thought to be related to mountain-folding.

Erosion in one area and deposition in another has been assigned as an initial agency in deformation. While some influence of this kind may be conceded, I think it is rather a localizing influence than a fundamental one. If wrinkling must take place from other causes, quite possibly previous erosion here and deposition yonder may localize the wrinkling. But that is quite apart from fundamentally causing the wrinkling. Reasons are growing yearly in cogency why we should regard the earth as essentially a solid spheroid and not a liquid globe with a thin sensitive crust. I think we must soon come to see that the great deformations are deep-seated body adjustments, actuated by energies, and involving masses, compared to which the elements of denudation and deposition are essentially trivial. Denudation and deposition seem to me clearly incompetent to perpetuate their own cycles. It seems clear that diastrophism is fundamental to deposition, and is a condition prerequisite to epicontinental and circum-continental stratigraphy.

Diastrophism thus seems to me fundamental both to stratigraphic development and life development. Diastrophic action seems to be the forerunner of both these standard means of correlation. It therefore seems to be the ultimate basis of correlation. The criteria of this correlation include at once its own specific criteria, the criteria of stratigraphy as dependent on diastrophism, and the criteria of paleontology as modified by the direct and indirect effects of diastrophism.

CONCERNING CERTAIN CRITERIA FOR DISCRIMINATION OF THE AGE OF GLACIAL DRIFT SHEETS AS MODIFIED BY TOPOGRAPHIC SITUATION AND DRAINAGE RELATIONS[1]

WILLIAM C. ALDEN

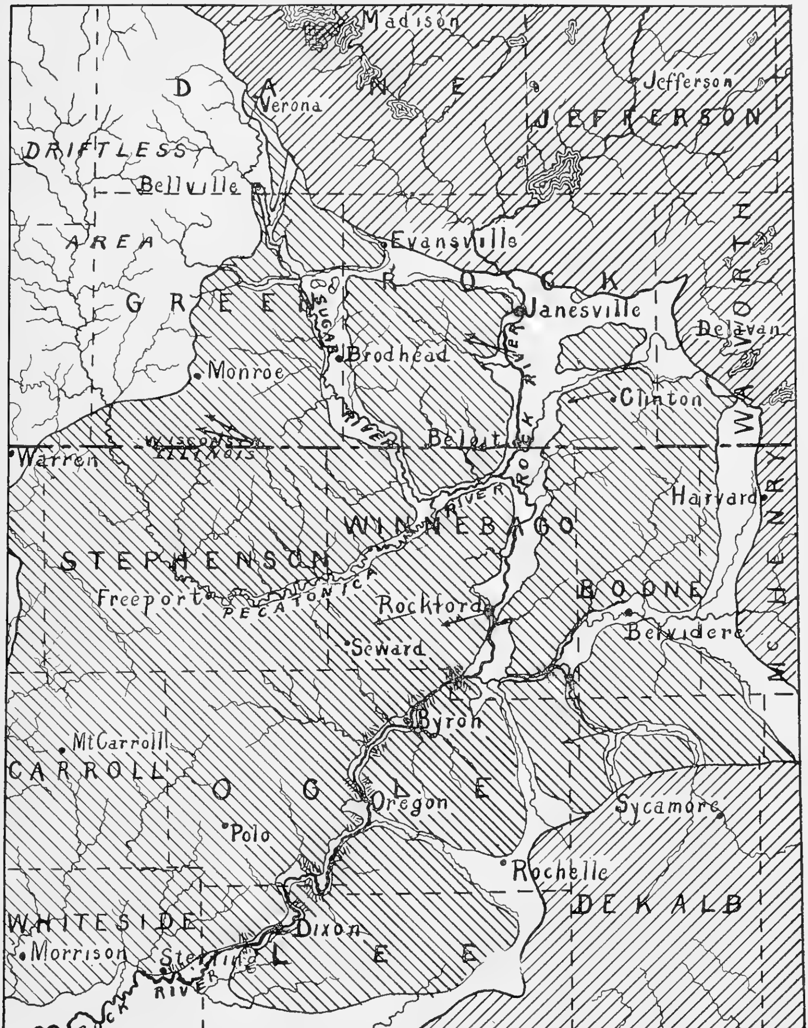
Between the limits of the drift sheets of Wisconsin age in southern Wisconsin and northern Illinois and the Driftless Area there is exposed a deposit of glacial drift of pre-Wisconsin age, having certain characteristics and relations which are of some significance in their bearing on the question of the criteria to be regarded as indicating difference of age in glacial drift sheets—a question of prime importance in the study of the Pleistocene deposits.

The drift under discussion mantles the slopes and uplands on either side of Rock and Sugar rivers and extends thence westward to the Driftless Area (Fig. 1). In southern Wisconsin the writer's observations were extended westward to the limit of the drift but in Illinois they were confined to a belt ten to twenty miles wide on each side of Rock River.

The filling of the main valleys is, in part at least, composed of outwash from the glaciers of the Wisconsin stage and this filling is not included in the present discussion. The upland drift consists principally of a sheet of moderately compact, highly calcareous clayey till which is practically identical in character and lithologic composition throughout the area examined by the writer.

In places, especially near the surface, the drift is loose and sandy. About 80 to 85 per cent. of the pebbles and bowlders imbedded in this till, as shown by many observations, and by the average of 71 analyses made by counting, are from the local limestones. About 3 per cent. are sandstones, shales, and quartzites, which are probably mostly of local origin, and about 14 per cent. crystallines of Canadian

[1] Published by permission of the Director of the U. S. Geological Survey. Read before the Geological Society of America, Baltimore Meeting, December 30, 1908.



Wisconsin drift sheets.

Illinoian drift sheet.

Driftless area, sand and gravel plains and terraces connected with the Wisconsin drift, and other alluvial flats.

Glacial striae, shown by arrows. Hachures show locations of rock gorges and rock bluffs along the post-Illinoian course of Rock River.

Fig. 1.—Glacial map of portions of southern Wisconsin and northern Illinois. (Boundaries for that part of Illinois not examined by the writer from Frank Leverett, "Illinois Glacial Lobe," *Mon. U. S. Geol. Surv.*, XXXVIII, Pl. XII.)

derivation. The limestone pebbles are mostly from the Galena and Trenton formations,[1] which underlie the drift throughout the greater part of the area, and partly from the Niagara limestone whose west margin lies a few miles east of the Wisconsin terminal moraines. The principal difference in the lithologic composition in the several parts of the area consists of a decrease in the content of Niagara limestone as one goes westward farther from the margin of that formation, with a reciprocal increase in the percentage of Galena and Trenton. Niagara pebbles are, however, seen in almost every exposure westward to the limit of the drift, the average shown by analyses being nearly 24 per cent. of the whole. The presence of this Niagara constituent with an occasional pebble of Devonian rock shows clearly the easterly derivation of the drift which is in consonance with the evidence of direction of the ice movement as shown by striae observed at several places. The striae, as shown upon the map, have bearings shifting from S. 75° W. east of Rock River and near Rockford, to due west at Beloit, N. 62° to 75° W. near Janesville, and N. 35° to 75° W. southeast of Monroe, as the ice closed in about the southeast side of the Driftless Area. At no place has the writer observed this till sheet to be overlain by any deposit other than sand, clayey loam, and loess, which could not have been, or probably was not derived from this drift by weathering or erosion.

It is quite possible, if not probable, that this till is underlain in part at least by older drift, but that question is not here under discussion. So far as the writer has observed there is no good ground for differentiating the drift exposed at the surface into deposits of more than one stage of glaciation. No intercalated soils, weathered zones, vegetal or other fossiliferous deposits are known to separate one part of this drift from another. Such as have been penetrated in wells or otherwise located occur beneath considerable thicknesses of this drift and probably represent an earlier stage of deglaciation.

The drift under discussion is clearly older than that bordered by the Wisconsin terminal moraines on the north and east, and it is believed to correspond in age with the Illinoian drift sheet which covers so large a part of Illinois farther south. There are, however,

[1] The Paleozoic formations are referred to in this article by the names in use for them in eastern Wisconsin by the Wisconsin Geological and Natural History Survey.

certain differences in the topography, amount of erosion, and depth and degree of surficial alteration of this drift in different parts of the area, which are very confusing when one attempts to apply the usual criteria for the discrimination of the age of drift sheets and which might be, and indeed have been considered indicative that this drift represented more than one stage of glaciation. It is the purpose of this paper to point out the differences and to suggest an interpretation of them which may perhaps find application in other areas.

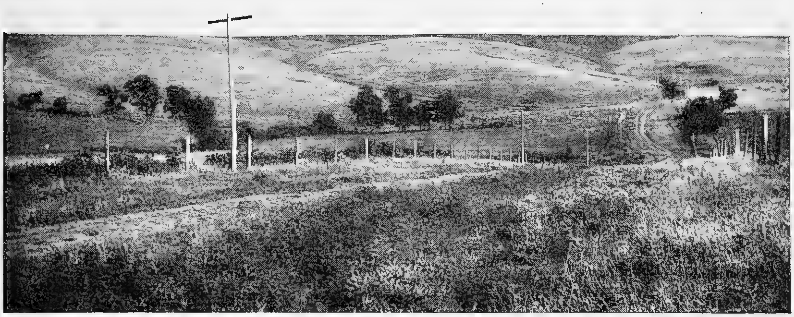


Fig. 2.—Erosion topography on Galena and Trenton limestones thinly covered with Illinoian drift three miles east of Monroe, Wis. Very little if any of the upland plain remains not reduced to slope.

The first of these differences to be considered are topographic. The character of the valley bottoms is to be neglected as due to subsequent filling, only that of the slopes and uplands being considered. In that part bordering Sugar River and extending thence westward to the Driftless Area the surface is much dissected with reliefs of 200 to 300 feet. At no places does a square mile of the upland remain and the drift-mantled slopes show drainage lines at intervals of 10 to 30 rods, which often notch the crests of the divides (Fig. 2). The topography as a whole closely resembles that of the Driftless Area to

the west (Fig. 3). Judging by the *topography* of the slopes and uplands alone one might say that the drift here was as old as the Kansan. Eastward to Rock River there is a little less relief and not quite so much dissection of slope, yet there is but little upland left and the topography looks mature. There are, however, in several places west of Rock River indications in the topography itself that the post-glacial drainage development is not as mature as appears from a more general view. At quite a number of places small drift

FIG. 3.—Erosion topography on Galena and Trenton limestone in the Driftless Area northwest of Monroe, Wis. Very little if any of the upland plain remains not reduced to slope.

dams in the valleys have diverted the drainage to one side where small gorges have been cut through adjacent rock spurs. These drift dams are small and their crests are usually well below the general upland level. The basins above these dams, however, are clearly not due to post-glacial erosion. There is thus positive evidence that the valleys were not entirely filled by drift and subsequently re-excavated, and hence that the present relief is only in small part due to post-glacial erosion. While there is thick drift in many places in the valleys, the upper slopes were usually but thinly mantled with drift

and the apparent maturity is largely due to the fact that the pre-glacial topography was but slightly masked and not wholly buried as it was within the terminal moraines of the later sheets. The post-glacial drainage, with the exception of these slight divergences, has followed pre-glacial lines, and here the gradients of the drift-mantled slopes were sufficiently high to favor rapid erosion.

East of Rock River the area covered by this same drift has a more youthful aspect, being a gently undulating upland plain with slight drumloidal ridges and occasional undrained sags. The borders of the tract are trenched by drainage lines but not greatly dissected. The amount of erosion of this upland, which extends southward to the valley of the Kishwaukee in southern Boone County, Illinois, appears but little greater than in similarly situated tracts within the Wisconsin terminal moraines, and, judging from these features alone, one would be very apt to conclude that the drift east of Rock River was considerably younger than that west of Sugar River, if not younger than that between the two streams.

Passing to the upland prairie west of Rock River in Winnebago, Stephenson, Ogle, Lee, and Whiteside counties, Illinois, one finds extensive, undissected tracts, nearly flat or very gently sloping (Figs. 4 and 5). Only the borders of these tracts, where abrupt slopes drop down to the valleys, appear to be eroded. From this condition there is a gradual transition northward to the rather mature topography between Rock and Sugar rivers. We have thus distinct topographic differences in different parts of the area which affect the interpretation of the glacial history.

On examining the degree of surficial alteration of this drift also notable differences appear. West of Rock River in Illinois, where there is such slight drainage dissection, the drift, beneath the thin coating of stoneless clayey loam or loess which is generally present, exhibits striking evidence of long exposure to leaching and oxidation. In many places but a scattering of pebbles lies between the loess or loam and the weathered surface of the limestone and these pebbles are all of the more insoluble kinds of rocks, mostly dense, fine-grained crystallines, cherts, quartzites, and vein quartz. Where there is a few feet of drift it is generally oxidized to a dark brownish color, is rather compact and sandy, not loose sand, but crumbling when dry into little

chunks, and the calcareous constituents are almost entirely removed. Where greater thicknesses are exposed, such as 5 or 10 feet or more, a very striking condition is revealed (Fig. 6). The body of the drift is found to be fresh, slightly altered, highly calcareous, clayey till, of light buff, pinkish, bluish, or grayish tint, in which the crystalline pebbles are sound with the exception of some of the diorites, or more basic granites. Fully 80 per cent. and often 85 to 90 per cent. of the pebbles in this unaltered part of the drift are limestone and these are

FIG. 4.—Illinoian upland drift plain of remarkably long, gentle, uneroded slope. The drift is probably of moderate thickness, overlain by a few feet of loess and underlain by Galena limestone. Three miles northeast of Seward, Ill.

undecayed and have smooth, clean surfaces, often highly polished and delicately striated. Within two or three feet of the top of the till and the base of the loess, however, there is an abrupt change in character and appearance. Passing upward the drift becomes dark brownish in color, the clayey matrix is found to be nearly or quite leached of its lime carbonate, and the few limestone pebbles which remain are either so rotted as to crumble between the fingers or the surfaces have been roughly etched by solution. In places only a soft yellow powder marks the former position of a limestone pebble. Within a few inches this grades upward into a dark-red layer from

which every particle of limestone including the pebbles has been removed, leaving only a small amount of sticky red clay, the residuum of complete disintegration of the limestone, binding the insoluble constituents, sand grains, quartz, quartzite, chert, and dense, fine-grained crystallines into a compact gritty mass. This layer is usually about 2 feet, sometimes 3 feet in thickness, and the change from the unaltered drift below takes place with remarkable abruptness generally within less than a foot—often within the space of a few

FIG. 5.—Illinoian upland drift plain, five miles west of Rockford, Ill. Galena limestone covered with 1 to 40 feet of drift. There are here extensive tracts of upland and long gentle slope but little affected by erosion.

inches. The red till is not a distinct deposit, for the change is usually gradual, though occurring within so small a distance. If the high percentage of calcareous material present in the unaltered part of the till is supposed originally to have continued to the surface of the deposit, as there is every reason for thinking it did, then this residual layer of insoluble constituents must represent but 20 per cent. of the thickness subjected to alteration. In other words, the 3 or 4 feet of residual till represents the concentration of the insoluble constituents in an original thickness of 15 or 20 feet of unaltered till. Even if for conservatism we consider the calcareous and other soluble

material as comprising but two-thirds of the unaltered drift the amount of alteration accomplished is considerable in reducing a thickness of 9 to 12 feet to 3 or 4 feet of residuum. This is much greater than the amount of alteration of the Wisconsin drift and indicates a much longer time of exposure, a length of time seemingly out of harmony with the amount of erosion which has been accomplished in this part of the area—for this residual drift is well developed where the

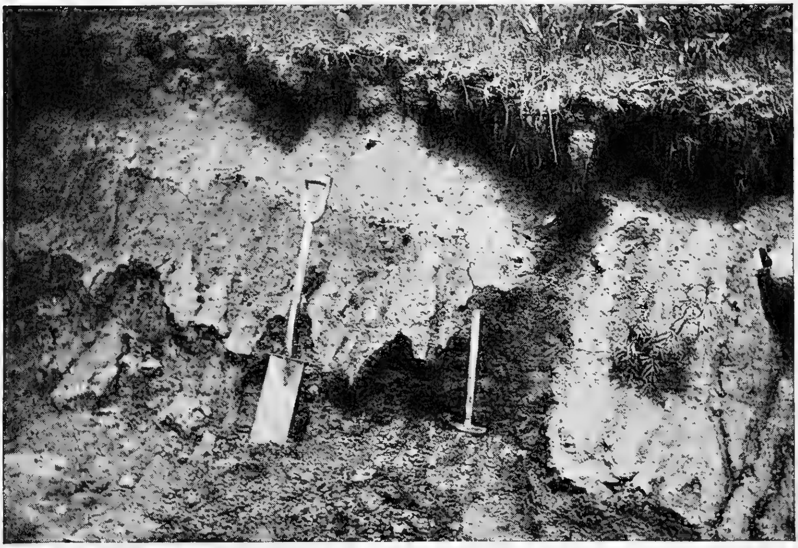


FIG. 6.—Exposure of Illinoian drift one-half mile south of Seward, Ill. The section shows loess $1\frac{1}{2}$ feet—dark-red, residual, weathered Illinoian till from which all limestone pebbles and finer calcareous material have been removed by solution, 2 to 3 feet—buff calcareous till with abundant pebbles of Niagara and Galena limestone. The length of the hammer, 16 inches, shows the zone of gradation from residual to unaltered calcareous till.

plains are least dissected by erosion. We have thus the combination of rather old drift and very young topography.

Added to these confusing conditions, one examining this tract west of Rock River in Illinois, especially along the borders of the upland, and in that part west and northwest of Rockford, frequently finds unaltered till coming right up to the surface or to the base of the thin coating of loess or loam, or else the unoxidized till has only the calcareous material of the clayey matrix leached out to depths of one or

two feet, while the limestone pebbles are fresh and sound. There are also occasional eskers and knolls of fresh limestone drift rising 5 to 25 feet above the surrounding plain of weathered drift. The relations are such that one might easily be led to the conclusion that the old drift sheet was overridden by a later advance of an ice sheet, which was thin and caused but little removal of the pre-existing drift, and which, on melting, left a scattered deposit of fresh drift upon the old.

East of Rock River where the most youthful topography is found the extremes in degree of weathering above noted are less frequently seen, there being the more usual combination of oxidation to a dark buff or brownish color and fairly complete leaching of the fine calcareous elements from the clayey matrix, but without removal of the limestone pebbles, though the surface of such pebbles in the upper part of the zone of weathering may be somewhat etched by solution. In some exposures the upper part of the drift is reduced to the residual condition and a few instances were noted where the matrix was leached of lime carbonate to depths of 10 to 15 feet, but this is rare. The average depth of surficial alteration east of the river is 4 or 5 feet. Were exposures more frequent in the uneroded parts of this upland tract the average amount of alteration might be found to be greater than this.

In the tract between Rock and Sugar rivers where the topographic development appears considerably more mature, and between Sugar River and the west limit of the drift where the amount of dissection seemingly approximates that of the Driftless Area, the drift on the slopes and crest is generally very thin, often little more than scattered pebbles, mostly of the insoluble varieties between the loamy clay soil and the weathered surface of the limestone. In many places, however, especially on lower slopes and in the valleys, considerable thicknesses of drift remain, sometimes 100 to 200 feet or more. Where even a few feet of this till are exposed the unaltered part is found to be the same highly calcareous drift as seen elsewhere. Tests at 25 or 30 exposures show the matrix of the till to be leached of its calcium carbonate to an average depth of about 4 feet, but the limestone pebbles are not removed. This depth includes the thin coating of brown non-calcareous loamy clay which generally overlies the drift

north of the state line. The leached top of the till is usually oxidized to a buff or brownish tint, but beneath this there is little or no evidence of alteration. At a few of the exposures basic crystalline pebbles in the weathered zone are considerably disintegrated but most of the crystalline and limestone pebbles are fresh, clean, and sound, showing little more alteration than in the late Wisconsin drift. Nowhere in this part has the residual condition of weathered drift been found so well developed or at least so well preserved as it is near Rockford, Illinois.

Taken altogether there is in this area of pre-Wisconsin drift a rather confusing lot of differences which must be harmonized if one is to reach any definite conclusion as to the relative age of the drift exposed. The unaltered drift is practically identical in character and lithologic composition throughout, the only differences in the latter being such as would be expected from an ice sheet moving in a westerly direction across the different rock formations which underlie the drift in different parts of the area or immediately to the eastward. The only questionable element is the derivation of quartzite pebbles, which need not be considered in this connection.

The differences in the present topography appear to be due very largely to differences in the pre-glacial topography which in the northwest was only mantled by the drift and not entirely obliterated; and in part to a retardation of erosion in certain parts of the area due to the relocation of Rock River, following the melting of the Illinoian ice sheet.

The character of the pre-glacial topography depends largely on the relations of the limestones and sandstones to the zone of erosion. The greater part of the area, that is, the slopes and uplands, is underlain by the Galena and Trenton limestones. These and the underlying formations have very low dips, curving over the low broad axis of the southern end of the Wisconsin island. Going toward this island, that is, up the low dip, the edges of the formations are beveled off and successively lower formations rise in the zone of erosion. The slopes developed on the limestones were rather long and gentle, but where the friable St. Peter sandstone rose into the higher levels there was more rapid erosion, a steepening of the slopes, and a greater amount of dissection was accomplished. This standstone rose well up in

the slopes north of the state line and here also Rock River cut down into the Potsdam sandstone, so that the uplands of Rock and Green counties west of Rock River were much dissected and almost wholly reduced to slope. East of Rock River, however, the southeasterly dip depressed the St. Peter sandstone in the east slope of the valley and carried it wholly below the bottom of the pre-glacial valley which bordered the eastern upland on the east in Walworth and McHenry counties. This confined the erosion more largely to the horizon of the limestones and as a result there was less dissection east of the river and much of the upland plain was left. Similar conditions resulted from the southward dip south of Pecatonica River on the west side of the Rock Valley. The St. Peter sandstone comes up again locally between Byron and Dixon, Illinois, but here other relations control the final result. The deposition of the drift sheet under discussion mantled these slopes and uplands but, as has been shown, the pre-glacial topography was only masked, not wholly obliterated, so that subsequent drainage for the most part followed earlier courses. Thick deposits were preserved in the valleys, but in the more dissected tracts, especially where the upper slopes were steep, conditions have been favorable for the accomplishment of considerable erosion.

Not only did the character of the pre-glacial topography affect erosion of the drift, but the relocation of Rock River, the master stream, which followed the retreat of the ice front had also some effect. When the glacial margin was melted back to the east side of the pre-glacial Rock Valley above the mouth of Kishwaukee Valley south of Rockford, the accumulated waters from the blocking of the drainage and melting of the ice found outlet across a series of cols and along the intervening valleys between Rockford and Sterling, so that the post-Illinoian stream became located along a new course, that which is now followed between Rockford and the Mississippi. In deepening its valley along this line the river was forced to cut gorges in limestone and sandstone at several points. There is some evidence that this cutting began 100 feet or more above the level of the present stream. Just how much below this level these gorges were cut before the outwash gravels of the Wisconsin stage came in is not known, but it is evident that their erosion must have retarded the work of the main stream and its tributaries throughout the area under discussion.

The fact that almost all of the area west of the Rock and north of the Pecatonica had previously been reduced to slope gave opportunity for considerable erosion there, despite this retardation, but elsewhere the slow process of working back into uneroded uplands had to be undertaken and as a consequence only the margins of the upland tracts have been dissected, while the upland plains, though fairly well drained, are still largely untouched by erosion.

In the relation of the rate of surficial alteration of the drift by leaching and oxidation to the rates of removal of the upper part of the drift by surface wash under these different conditions prevailing in different parts of the area may be found the explanation of the apparent discrepancies noted when attempting to apply the criteria for determining the age of the drift sheet. The discrepancies are apparent rather than real, yet they are none the less confusing. The difficulty is to make the proper allowances and draw the right conclusions.

In the region south of the state line where the extremes of fresh or little weathered drift and of drift reduced to a residual condition are found at the surface or immediately underlying the loess or loamy clay in neighboring exposures, careful examination reveals the fact that in many places at least where the drift is so fresh the topographic relations are such that the weathered upper part may have been removed by slope wash. That it really was so removed seems clear, for many, if not all, of these exposures of fresh drift are on slopes, and where the exposures extend up the slopes as along roads one often finds the fresh drift disappearing under a layer of weathered drift higher up. In some places where the road runs along a gentle slope, where it does not look as though much wash had occurred, fresh drift is exposed at the surface on the down-hill side, while on the up-hill side thoroughly leached and oxidized residual till extends to the full depth of the shallow cut. It may be that a relation so obvious appears scarcely worthy of mention, yet it is one that may be readily overlooked in such situations as here where the erosion of the drift occurred before the deposition of the loess, and the latter obscured the slight topographic expression that resulted.

In the cases of the unaltered drift composing the knolls and ridges no evidence other than the freshness of the drift was noted which

might be taken as indicative of their later origin. In these cases it seems that, even if the weathered surficial part has not been removed by erosion, the configuration and structure of the slight elevations may explain their lack of weathering. In the first place, the rounded surfaces of the knolls and ridges rising above the plain shed most of the water falling on them much more readily than do the surrounding plain tracts, especially where the latter have such long gentle slopes such as characterize the area in question. The gravel of the knolls is particularly loose and open so that such of the meteoric water as penetrates, percolates through and out of the gravels very readily and has but a comparatively small contact with the surface of the calcareous particles or pebbles. This is true not only because of the large interspaces allowing rapid passage of water, but also because the total amount of surface exposed by the pebbles is far less than that where the material is finely comminuted as the rock-flour matrix of the till. The result is that while the waters slowly percolating downward into the calcareous till on the plain tract may have relatively large solvent action, so as to remove the finer particles and even the limestone pebbles to the depths indicated above, the limestone pebbles of the knolls and ridges continued unaltered beyond a small amount of cementation in the lower parts of the deposit by lime carbonate carried down from above. On the nearly flat or gently sloping plains surface wash seems to have been reduced to the minimum, while the slow process of leaching out the calcareous elements and oxidizing the ferruginous constituents had its maximum effect. Here the till slowly rotted down. Besides the part which was removed by solution, some of the finest silt may have been carried away by surface wash. This was deposited in the valleys while much of the insoluble part of the clay and the more resistant sand grains and pebbles, the residuum of the leaching process, was left on the unaltered drift.

In those situations, where the topography and the constitution of the drift were such that the rate of leaching and oxidation exceeded the rate of removal of the weathered part by wash, such a residual layer was developed. Where the rate of removal was more rapid or where the two processes nearly balanced each other, fresh drift is exposed at the surface. Where the relations were such that the rate of removal lagged behind the process of alteration, but not so far that

there was time for the reduction of the weathered drift to a residual state, such as seems to have been the case on the moderately mature erosion topography west of Rock River in southern Wisconsin, there is the usual condition of leaching of the clayey and sandy matrix to moderate depths and oxidation only to the degree of changing the original pinkish, bluish, or grayish color to a buff or brownish tint.

It is thus evident that the apparent alteration of a single drift deposit by weathering and erosion may vary considerably in different and often closely adjacent parts of a single drainage basin in the same length of time, even where the differences in elevation are but slight and where the climate is the same. It is true that one cannot always see just what the particular relations were which resulted in the different degrees of alteration at two different exposures, and the observed differences are frequently not just what one would expect from reasoning along the line indicated. However, it is well to bear in mind the fact that such differences do occur where there appears to be no adequate ground for assigning the differently affected deposits to distinct stages of deposition. Caution must be used in applying the criteria and good and sufficient grounds for the differentiation should be observed. It is not necessary to enumerate these criteria in this paper. They have been fully treated by competent authorities in other places. It seems to the writer particularly hazardous to assign a more recent age to what appears to be a thin and scattered deposit of fresh, unchanged, or little altered drift, exposed here and there, when the main deposit of the area in question is of similar lithologic composition and has been considerably altered by weathering and erosion, unless a weathered zone, old soil, or vegetal deposit is observed clearly intercalated between the two drifts. It may not be easy to show that a weathered part has been removed by erosion at the particular places where the fresh drift is observed, or that the conditions for erosion, leaching, and weathering were such that no alteration of the upper part of the drift *in situ* was ever accomplished, but the burden of proof certainly lies with the interpretation which postulates distinct stages of glaciation. Differences in texture and conditions of deposition are particularly unsafe, since almost every conceivable variation of this kind may be found in different parts of what is

unquestionably a single drift sheet. As has been shown in this discussion, careful scrutiny of the topography, the drainage, and other relations which may affect the apparent amount of surficial alteration by weathering and erosion in the area under investigation may yield an adequate explanation of the differing phenomena without the postulation of distinct stages of glaciation.

THE BEARING OF THE STRATIGRAPHIC HISTORY AND INVERTEBRATE FOSSILS ON THE AGE OF THE ANTHRACOLITHIC[1] ROCKS OF KANSAS AND OKLAHOMA[2]

J. W. BEEDE

The present interest in this subject is such as to warrant a brief review of the broader features as determined by the preliminary survey of the data at hand with regard to the age of the Kansas-Oklahoma rocks, before completing the final work upon them, to give an idea of the present status of the problem and suggest some of the larger features to be worked out.

I wish to acknowledge the assistance and co-operation of Professor C. N. Gould and through him of the Oklahoma Survey, which have contributed much to both data and suggestion, as well as material aid in pursuing these studies. For the privilege of carrying on my Kansas studies I am indebted to Dr. Haworth and the Kansas Survey. This manuscript has been submitted to Professors Haworth, Gould, and Prosser for their suggestions and criticisms, which have been incorporated. The general considerations have been freely discussed with Professor Cumings, and he has also read the manuscript and offered valuable suggestions.

In order to arrive at a comprehensive understanding of the invertebrate fauna of the rocks supposed to be of Permian age in the western Mississippi valley it is necessary to understand the stratigraphic history and the nature and range of the faunas of the underlying rocks as well. The discussion of this subject forms a necessary introduction to the Permian question.

[1] This term was introduced by Waagen and he has been followed by Diener of the Indian Survey; it is used to designate the Carboniferous and Permian deposits under a single head, when it is desirable to refer to them in that way.

[2] Published by permission of the state geologists of Kansas and Oklahoma. A portion of this paper was read at the Baltimore meeting of the Geological Society of America.

STRATIGRAPHIC CONSIDERATIONS

Several years ago it was discovered that the Cherokee shales were not the oldest deposits of the western Coal Measures or Pennsylvanian rocks. While it was known that the unconformity between these shales and the Mississippian rocks below was a profound one, yet its true significance was not realized until the discovery in Arkansas and eastern Oklahoma of a great series of underlying rocks of Pennsylvanian—Lower Coal Measures—age. The result of the discovery is to restore the Lower Coal Measures to the trans-Mississippi section, leaving the Cherokee shales and perhaps some associated strata representing the Middle Coal Measures—"Middle Upper Carboniferous" of European geologists—of Europe.

While this latter fact has been determined largely by paleobotanic[1] evidence and that derived from the cephalopods[2] it is believed that the trend of the evidence furnished by the invertebrates is, in general, in the same direction.

The Cherokee shales are a thick (400–500 feet) series of shales with some sandstones and coal, on the whole unfavorable to the existence of clear-water marine faunas. Indeed much of the region stood at about sea-level for considerable lengths of time, as is evident from the plant remains and coal deposits distributed through the rocks as well as by ripplemarks and other physical evidence. However, marine conditions and faunas appeared especially during its later history.

Following the deposition of the Cherokee shales the sea transgressed and the Fort Scott limestone was deposited. This limestone is of considerable thickness and carries a rich marine invertebrate fauna. Following the Fort Scott limestone there occurred rythmic recessions and transgressions of the clearer marine waters throughout the Kansas region, resulting in the deposition of alternate clay shales and limestones with, rarely, fine sandstones and coal. The shales vary from 40 feet to 200 or more feet in thickness, and the limestones from two to 40 or 50 feet in thickness. The shales are clayey, sometimes carrying considerable fine sand, and are gray to

[1] David White, *Mon. XXXVII, U. S. Geological Survey*, 1899.

[2] J. P. Smith, *Mon. XLII, U. S. Geological Survey*, 1903.

black in color. Blue, gray, and drab are the prevailing colors. The limestones are blue or gray weathering to a buff, and are sometimes nearly white. They are almost invariably well lithified, more or less crystalline, and are not very porous. The thickness of the whole succession, up to the Americus limestone, is over 2,000 feet or 2,500 feet, including the Cherokee shales.

The limestones do not all continue to the southern limit of Kansas, some of them pinching out before reaching the Oklahoma line and others soon after crossing it. Few of them pass beyond the Arkansas River in that state. It seems that the central part of the Kansas basin may have been to the northwestward during later Pennsylvanian time, since the shales frequently become thinner, and the limestones thicker in that direction, though this cannot be said of the lower part of the section. Above the Americus limestone the succession of limestones and shales continues for about 700 feet. However, the shales become more calcareous and marly, the limestones more porous and less crystalline; massive gypsum beds are intercalated, and coal in quantities is wanting. The limestones also weather white.[1] These changes are significant of decided physical or climatic changes, as the local pools of the lower horizons showed no tendency to concentrate and form massive gypsum deposits. Probably, also, the changed aspect of the limestones is indicative of these altered conditions. The first large deposits of gypsum occur just above the Cottonwood limestone in the lower part of the Garrison formation (Neosho member). Above these are the Wreford limestone, Florence flint, Fort Riley and Winfield limestones, heavily charged with chert, and separated by thick layers of shale. The outcrops of these formations form the "Flint Hills" of the eastern part of central Kansas. Over these strata are two soft limestones with three intervening shale beds and a variegated, brecciated, thin limestone. These are grouped in the Marion stage, and end the regular succession of limestones and shales. Over the rocks of the Marion stage lie the Wellington shales, probably several hundred feet in thickness, composed of blue, green, and some red shales. Upon these shales lie 1,400 feet of Red Beds in Kansas. The upper part of the Red

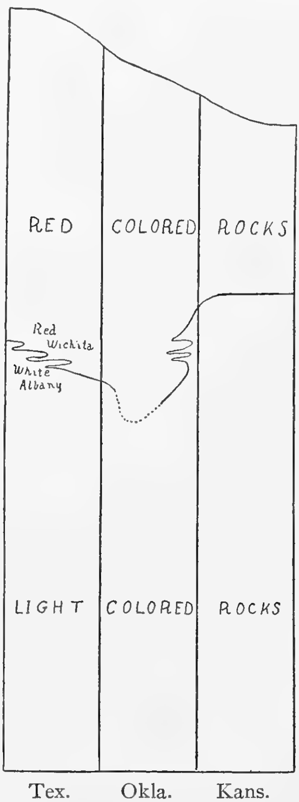
[1] Adams called attention to these lithologic features, in *U. S. Geological Survey, Bulletin 211*, pp. 70–78, 1903.

Beds does not occur in Kansas but is found in western Oklahoma and the Panhandle of Texas.

The whole of the lower succession of shales and limestones forming lowlands and low escarpments divide this section of continuous sedimentation into short stratigraphic units of great lateral extent convenient for paleontologic study.

In Oklahoma different conditions prevailed during much of the time represented by the Kansas deposits, above the Cherokee shales.

Passing from Kansas to Oklahoma the light-colored shales and limestones of the upper part of the Kansas section grade off into red shales and sandstones. The lowest horizon in Oklahoma at which the red sediments predominate is unknown, inasmuch as the strike of the rocks is but little west of south, and the Red Beds protrude eastward in central Oklahoma as a sort of embayment, especially north of the Arbuckle Mountains.[1]



In the region south of the western end of the Arbuckles the Red Beds lie unconformably upon the tilted and eroded Pennsylvanian rocks. It appears that the Albany-Wichita sea of northwest Texas transgressed over this region during a time of slight depression, the waters covering the western end of the Arbuckle Mountains, swinging eastward on their northern slope as far as the Seminole Country. According to Cummins there is no unconformity in Texas between the lighter

[1] For the citation and review of the literature on the Permian of Oklahoma and Texas, see the author's paper on the "Invertebrate Paleontology of the Upper Permian Red Beds of Oklahoma and the Panhandle of Texas," *Kans. Univ. Sci. Bull.*, IV, pp. 115–48, 1907. The geology of the Arbuckle and Wichita mountains is described by Mr. J. A. Taff in *Professional Paper 31*, *U. S. Geol. Surv.*, 1904.

sediments and the Red Beds, the transition between the Albany and the Wichita being a gradual lateral one. The transgression of the Red Beds in the Arbuckle Mountains may, then, be regarded as a northeastern or eastern encroachment of the Wichita sea—or conditions of sedimentation, as all these beds may not be marine. Whether this Arbuckle unconformity extends northeastward to the easternmost limit of the Red Beds has not yet been determined, and indeed may be very difficult to determine, where the unconformity would resolve itself to a mere disconformity of layers of shales, and perhaps accompanied by a greater or less reworking of the lower deposits. Gould, who has been over this region between the Arbuckles and the Arkansas River many times, states that he knows of no unconformity. If no unconformity exists to the north of the Arbuckle Mountains, it seems probable that the first Permian emergence began here and the deposition of the Red Beds in the Seminole Country is the first record of it, the later sediments from the Arbuckles reaching farther north. Regarding the gradation of the upper part of the Kansas section into the Red Beds in northern Oklahoma, there can be no doubt whatever, and the same is probably true of the central part of the state.

The Arbuckle and Wichita mountains are probably the source of much of the red sediment, in which they are partially buried, and the former mountains are directly responsible for the eastern extension of these beds into central Oklahoma. The extent to which the lighter-colored sediments of Kansas and Texas are replaced by red sediments in Oklahoma and near it, represents in a rough way the limits of the influence of these mountains on the deposits of the time by the spread of their sediments. By the time the deposition of the light-colored sediments had ceased the conditions had become such that nearly all the sediments derived from the land surrounding this basin were red.

In the Oklahoma region the deposition of red sediments began, perhaps, as low as the Howard or Topeka limestones, and perhaps as high as the Emoria or Americus limestones. The deposits then seem to be uninterrupted until the unconformity below the Dockum beds (Triassic) in the Texas Panhandle is reached. Some of these beds appear to be of subaerial origin, as has been shown by Case,[1]

[1] *Bull. Amer. Museum,* XXIII, pp. 659–64, 1907.

while others are certainly marine. Careful petrologic study will probably demonstrate that much of the arenaceous material is wind-blown sediment, more or less reworked by currents or waves as the regions were submerged or flooded. That the sea ever covered the entire area from Kansas to southern Texas and New Mexico at one time may be questioned. If it did, the sediments contained were of such a nature and abundance, or the waters so concentrated as to preclude the free migration of a normal marine fauna throughout the basin. That marine conditions prevailed, at least locally, is demonstrated by the Whitehorse and Dozier faunas.

In Texas normal deposits were laid down in higher horizons than in Oklahoma, and in Kansas there are reasons for believing that the light-colored sediments were laid down at an even later date than in Texas. These conditions are illustrated in the subjoined table, showing a vertical section of the Carboniferous and Permian rocks of the three states.

The extent of this post-Pennsylvania basin seems to have been very great. It included much of Kansas ($\frac{2}{3}$), Western Oklahoma, much of western Texas, and all of New Mexico, Colorado, and Wyoming east of the Rocky Mountain axis. In area it probably aggregated 300,000 square miles.

Together with the varied physical conditions of these three regions went corresponding faunal peculiarities. In the Albany division of the Texas rocks the Pennsylvanian elements of the fauna seemed to persist, while they are largely wanting in their equivalent beds, the Wichita division. A similar thing occurs in the clear-water beds of northern Oklahoma and southern Kansas, north of the Red Beds. Aside from this general fact it should be noted that along the region of the Red Beds and light sediment (litoral?) contact, some of the Pennsylvanian elements of the Kansas fauna persisted much longer than in the same rocks to the northward. The fauna of any given horizon above the Elmdale formation varies very sensibly as we pass from the Nebraska to the Oklahoma line, both in abundance of specimens and species, and in the general aspect of the faunules as well. This is to be expected in the light of the intercalation of massive gypsum beds as low as the lower part of the Neosho member in the northern region. From it we would infer that the waters of the

northern-main marine part of the basin were somewhat more concentrated than at its southern shore.

OUTLINE OF FAUNAL HISTORY

One of the most striking features of the Kansas Anthracolithic fauna is the great range of a relatively large number of species. In regions of instability of the earth each successive change of physical conditions brings in new faunas, tending to eliminate their predecessors, and bringing about more rapid and complete faunal changes than in interior regions of continental stability. In these latter regions the effects of these crust movements are minimized and their effect upon the faunas is proportionally less marked. Consequently one accustomed to the study of the faunas of marginal continental deposits may easily underestimate the value of the less complete faunal changes occurring in rather remote epicontinental basins.

In the regions of great instability it is rarely, if ever, that species show their whole life-history, from its inception to its natural termination, in an unbroken succession of rocks. In an interior region, like the Kansas basin under discussion, persistent species do occur exhibiting this life-history fairly completely, and are significant of the lapse of time represented by the deposits. Many of the forms which are so persistent in the Kansas rocks, especially among the brachiopods, represent the latest stages of the life-history of their genera or families which rarely, if ever, give rise to new phyla, since they have passed their culmination and entered upon their decline. They are therefore not to be expected to give rise to many new forms under ordinary conditions (in the higher deposits) and, having largely lost their adaptability, perish under untoward conditions. Under this class of organisms come the Productidae, Strophomenacea, and Orthidae, and the genera Seminula, Cleiothyris, Hustedia, Ambocoelia, Spirifer, and Pugnax, which are unknown above the Permian. Nearly all these groups have their maximum development in the Pennsylvanian or earlier deposits. Among the bryozoans this is still more strikingly true. The Fistuliporidae, Batostomellidae, Rhabdomesontidae, Fenestellidae, and Acanthocladiidae disappear before the initiation of the Mesozoic, and nearly all of them have culminated before the beginning of the Permian.

In strong contrast with the brachiopods and bryozoans stand some of the pelecypods. They are not paracmic and do differentiate with changing conditions, and constitute the main characteristics of the upper part of the Kansas section. This differentiation seems to have been in the main closely parallel in direction with the development of the Permian pelecypods of Europe.

It is to be regretted that the ammonoid cephalopods were nearly wanting in the Kansas basin throughout its faunal history. The trilobites are represented in the upper rocks by a single species of Griffithides, the last (so far as the Kansas rocks are concerned) of the Proetidae. Many of the ostracods are to be looked upon as degenerate or atavistic, and probably are not found above the rocks of the Chase stage.

The study of the stratigraphy of the Kansas basin and its surrounding deposits and its fauna, has convinced me that the foregoing general considerations must be taken into account in order to reach a rational understanding and interpretation of its faunal history. It should also be held in mind that the evolution of a fauna, in so far as it is capable of evolution, in this great epicontinental sea is of as great significance, as the evolution of a fauna along similar lines about the islands and in the continental seas of Europe. On account of its limitations and relative paracmic condition the latest fauna of the Kansas basin, without free contributions from other regions which physical conditions seemed to prohibit, cannot be expected to contain the wealth of species characterizing cosmopolitan faunas.

In the study of the Anthracolithic section of Kansas the following stages and larger divisions here designated "series" have been made out. These divisions with their characteristic faunas are described in Vol. IX of the Kansas survey, in press at this writing.

The basal formation of the Kansas Pennsylvanian system is the Cherokee shales or Stage A. This stage is characterized by a preponderance of specimens of *Marginifera muricata* with an abundance of *Chonetes mesolobus,* etc. It might with propriety be called the *Marginifera muricata* Zone, as in no other horizon is this species the predominating one. Stage B is characterized by the introduction of a very large number of the most characteristic Coal Measures fossils, sixty species being added in its basal member, the Fort Scott

Permian	V	Well.	Wellington shales	
		Marion	Abilene conglomerate	
			Pearl shales	
			Herington limestone	
			Enterprise shales	
			Luta limestone	
	IV	Chase	Winfield limestone	
			Doyle shales	
			Fort Riley limestone	
			Florence flint	
			Matfield shales	
			Wreford limestone	
		J	Neosho member	Garrison formation
			Florena shales	
			Cottonwood limestone	
		I	Eskridge shales	
			Neva limestone	
			Elmdale formation	
Pennsylvanian	III	H	Americus limestone	
			Admire shales	
			Emporia limestone	
			Willard shales	
			Burlingame limestone	
			Scranton shales	
		G	Howard limestone	
			Severy shales	
			Topeka limestone	
			Calhoun shales	
			Deer Creek limestone	
			Tecumseh shales	
			Lecompton limestone	
			Kanwaka shales	
		F	Oread limestone	
			Lawrence shales	
			Kickapoo limestone	
			Leroy shales	
			Stanton limestone	
			Vilas shales	
			Allen limestone	
			Lane shales	
	II	E	Iola limestone	
			Chanute shales	
		D	Drum limestone	
		C	Cherryvale shales	
			Dennis limestone	
			Galesburg shales	
			Mound Valley limestone	
			Ladore shales	
			Bethany Falls limestone	
	I	B	Pleasanton shales	
			Coffeyville limestone	
			Walnut shales	
			Altamount limestone	
			Bandera shales	
			Pawnee limestone	
			Labette shales	
			Fort Scott limestone	
		A	Cherokee shales	
	Series	Stage		

limestone, and fifteen during the rest of the stage. Nineteen of these fossils are among the best-known Pennsylvanian species, such, for instance, as *Campophyllum torquium*, *Rhombopora lepidodendroidea*, *Stenopora carbonaria*, *Chonetes verneulianus*, *Dielasma bovidens*, *Meekella striaticostata*, *Acanthipecten carboniferus*, *Aviculopecten occidentalis*, *Schizodus wheeleri*, *Euomphalus catilloides*, and *Tainoceras occidentale.* One of the peculiarities of this stage is the occurrence of Chaetetes reefs, especially in the upper Fort Scott limestone. Another characteristic is the appearance of Foraminifera with the form of Fusulina, but with imperforate shells, probably belonging to the genus Fusulinella. These conditions maintain themselves until the close of the stage.

These two stages combined make up a definite faunal unit of a larger order which I have designated as "Series I." Fusulinella and *Chonetes mesolobus* are confined to it, and *Marginifera muricata* is never so abundant again. *Chaetetes milleparaceous* is comparatively rare in the rocks above.

The early part of Stage C is marked by another great influx of species which is more continued than that of the preceding stage, though the species are hardly as important. It seems very probable that at this time there was quite as general a sea connection between the Kansas sea and the rest of the world as at any time during the history of the basin. Such important species as *Lima retifera*, *Sedgwickia granosum*, and *Orbiculoidea convexa* are among those introduced—over thirty species in all.

Stage D is the most striking horizon in the Kansas succession. Oölitic conditions with their accompanying fauna invaded the region and give us a peculiar assemblage of fossils, some of which seem quite foreign to their surroundings. We have in the Drum limestone, or its equivalent, at Kansas City and vicinity, a well-developed Pseudomonotis fauna. These fossils usually characterize the Permian rocks of Europe. They are here found in rocks far below the Permian. Unlike the faunas of the rocks above and below, this fauna is strongly molluscan. Many of the species introduced disappeared with the muddying of the waters, while others returned intermittently, especially the species of Pseudomonotis which became very prominent in the Permian rocks.

Stage E forms the closing chapter of the conditions existing in these rocks. Here several of the species with which we have been dealing are found for the last time, examples being *Michilinia eugeneae*, *Conocardium parrishi*, *Lima krotowi*, *Cryptacanthia compacta*, and others.

These three stages make up Series II. It is characterized by the features already mentioned and in a negative way by the absence of species of extreme importance noted below, which occur in the rocks above.

Stage F is characterized by the absence of the species just mentioned and the introduction of *Chonetes granulifer*, one or two species of Enteletes, and the true Fusulinas. Some of these fossils color nearly every faunule of the succeeding rocks of the Pennsylvanian part of the section. Among other important species introduced were the Amblysiphonellas and other sponges, *Limopteria marian*, etc. The top horizon of the stage is remarkable for the last appearance of twenty species, and the first important development of the Fusulinas, a long, slender species, and the first abundance of *Chonetes granulifer*.

In Stage G an undescribed species of Strophalosia is the only permanent addition, while the loss of species amounts to twenty-eight (disregarding species peculiar to the stage), most of these being found for the last time in the Howard limestone, its topmost member. Among these are many prominent Pennsylvanian species, as *Squamularia perplexa*, *Productus pertenuis*, *Campophyllum torquium*, etc.

In Stage H, *Sedgwickia altriostrata* is added in the Burlingame limestone and Bairdia, Beyrichiella, and Meekopora appear in the uppermost bed. These latter additions may be well associated with the succeeding stage as they are found in the marly layer resting upon the Americus limestone, and are the precursors of other important introductions which follow.

Stages F, G, and H comprise Series III. From what has preceded it is seen to be characterized by the introduction or development, in its basal part, of three of its main faunal elements and is set off from the succeeding series by the fact that at least one hundred and seventy-five of its species are unknown in the rocks above.

In Stage I four species first appear which play a very important

rôle in the later faunas. They are: *Pleurophorus whitei, Aviculopicten nebraskensis,* and *Myalina permiana* and a species usually referred to *M. aviculoides.* A species of Schwagerina associated rather closely with a Permo-Carboniferous micro-foraminiferal fauna also occurs in this stage. During this stage, too, some of the most characteristic and cosmopolitan species of the Kansas Pennsylvanian are found for the last time. Four of these are: *Spirifer cameratus, Hustedia mormoni, Spiriferina kentuckiensis,* and *Chonetes geinitzi* (not *C. laevis* of Keyes).

Stage J is important in that it records the final reduction of the Fusulinas to the ranks of a rare species, in possessing a very abundant ostracod fauna of a late type, and the final occurrence of ten or fifteen species.

The Chase stage, the upper part of Series IV, is characterized by the development of the pelecypods and the lessening of the rôle played by the Molluscoidea. The abundant forms are: a retrogressive form of *Seminula argentia,* a species of Fenestella, *Productus nebraskensis, Bairdia beedei* or an allied form, with other ostracods, *Septopora* sp., *Derbya multistriata, Mylina permiana, Aviculopecten nebraskensis* and a form of *A. occidentalis, Myalina aviculoides?,* several species referred to Bakewellia, *Pleurophorus whitei,* with two other species, *Pseudomonotis hawni, Edmondia nebraskensis, Aviculopinna knighti, A. nebraskensis,* Producti of the *semireticulatus* type, and a Derbya like *D. crassus* and a species of Rhombopora.

Above Series IV, the brachiopods and bryozoans and ostracods and other lower groups nearly disappear, leaving an impoverished pelecypod fauna. The fauna of the Red Beds of Oklahoma and the Panhandle of Texas, lying one or two thousand feet above the Marion stage, has already been described.[1]

The following table is expressive of the numerical relationship of Series IV to Series I–III:

	No. of Species		No. o Species	Species in Common
Series I	131	Series IV	141	51
Series II	237	Series IV	141	73
Series III	264	Series IV	141	85

[1] "Invertebrate Pal. Upper Permian Red Beds of Oklahoma and Panhandle of Texas," *Kansas University Sci. Bull.,* IV, pp. 115–71, 1907.

These figures are by no means expressive of the faunal character of Series IV, especially the part lying above Stage J. The nature of this fauna is such as to separate it sharply from any Pennsylvanian fauna known to me. For the characteristic fossils of the series as a whole we must add the "Permo-Carbon" micro-foraminiferal fauna described by Spandel,[1] probably from the Neva limestone, *Orbiculoidea manhattanensis, Pugnax swallowana* (Hall and Clarke's identity), *Meekopora prosseri,* and *Thamniscus octonarius.*

Considered as a whole the fauna of Series IV, however closely or remotely the individual species may be related to those of other regions, certainly exhibits the same general aspect as the Permian (including the Artinsk and Permo-Carboniferous) of England, Germany, and Russia.

Series IV is regarded as the equivalent of the Permo-Carboniferous of Europe which is classed by most European geologists as the lowest division of the Permian. Stages I and J are, perhaps, debatable ground on account of the great preponderance of Pennsylvanian species. However, the loss of 179 species (two-thirds its fauna) during the latter part of Series III and the introduction of distinctive Permian elements are considered as strong evidence pointing to the initiation of Permian conditions. If this is supplemented by similar plant evidence it should be referred to the Permian.

The Wellington is unquestionably referable to the Permian in the narrowest sense of the word and the Marion probably may be.

THE NORTH URALIAN SECTION

The Anthracolithic section of the Ural-Timen region of northeastern European Russia is as follows: The "Middle Carboniferous," Omphalotrochus horizon, Productus-Cora horizon, Schwagerina horizon, Artinskian, and Permian. The Artinskian constitutes the "Permo-Carboniferous" of Russia. The uppermost division of the Carboniferous is the Schwagerina horizon below which is the Productus-Cora—"Cora" of Tschernyschew—horizon. These two are sometimes referred to as the Fusulina limestone, and the lower as the Gschelian. Below them lies the Omphalotrochus horizon

[1] "Die Foram. des Permo-Carbon von Hooser," *Kans., N. Amer., Abhl. der Naturh. Gesellsch. in Nürnberg,* pp. (on separate) 1–20, 1901.

and beneath it the "Middle Carboniferous." The Artinsk is considered as a subdivision of the Permian.

The part of the section of particular interest to us is the portion including the "Cora," Schwagerina, and Artinsk zones. The relationships of these Upper Carboniferous beds of the Urals to the Artinsk is clear. The sandstones and conglomerates of the latter rest directly upon the calcareous deposits of the former. As has been so well shown by Krasnopolsky, the Permian period of eastern Russia is especially characterized by the uplift of the Ural Mountains from a series of islands to a continuous mountain chain. In the northern part, the Ural-Timen region—including the Timen Mountains—it was rapid and sandstones and conglomerates on the western flanks were the result. This permits a sharp differentiation of the deposits. In the southern region this sharp distinction is impossible as the uplift was very slow and the effects less noticeable, gypsum and dolomites being about the only lithologic indications of the changing conditions in the Donnez basin. In the north there is a sharp differentiation of the fauna in response to the sharply changed physical conditions, while in the south the differentiation is correspondingly more gradual and is produced by the mingling of the northern species of the Artinsk with the open-sea fauna of the Carboniferous. This makes the line between the Permian and Carboniferous harder to draw in the southern region. As Krasnopolsky argues,[1] the place to draw the line is with the first appearance of the Permian species. The conditions in northern Oklahoma, Kansas, and Nebraska were very similar to those of the southern Ural region.

As Rothpletz[2] has pointed out, and as further discussed by Diener,[3] the arenaceous fresh- and salt-water deposits of the Ural-Timen region and the Zechstein are not the normal open-sea deposits of the Permian period, but somewhere those conditions existed in which the percentage of Carboniferous elements in the fauna would be larger. They also point out that these deposits probably are to

[1] *Mem. Geol. Comm. Russ.*, Vol. IX, pp. 506 ff.

[2] Rothpletz, "Die Perm-Trias u. Juraform. auf Timor, etc.," *Paleontographica*, XXXIX, pp. 57 ff., 1892.

[3] "Diener, Himalayan Fossils," *Mem. Geol. Surv. India, Pal. Indica.*, Ser. XV, Vol. I, 1899–1903.

be found in the Asiatic region and in America. To a fair degree this seems to be true of the lower portion of the Permian (that part represented in the Kansas section) in America, and as Diener has shown, in the eastern Himalayas, and it is true of the Mediterranean region. The most typical marine Permian fauna of this age in America is found in the Guadalupe Mountains of Texas and New Mexico.[1] It is the failure to recognize these dual conditions that has caused much of the controversy over the Permian question.

In the Kansas rocks as well as those of Oklahoma and Texas, only the basal part is typically marine. The typical marine facies of the beds extend quite as high in the Kansas section as in that of Texas. Local incursions of marine conditions occur later in western Oklahoma and Texas than in Kansas.

The faunal relationships of the Kansas section are such as to lead us to suspect that an interrupted intermigration requiring considerable time in its consummation occurred between the European and Kansas regions. This fact tends to complicate direct correlation and it is questionable if minor stages can be correlated closely with those of Europe. Less trouble will probably be encountered in the final determination of the separation of the Permian—in the broad sense of the term.

COMPARISON OF FAUNAS

A collection of Foraminifera, probably from the Neva limestone, was studied by Erich Spandel.[2] Some of these were found to be distinctly of Carboniferous and some of distinctly Permian affinities, and he concluded that the rocks from which they come are of Permo-Carboniferous age. He was sufficiently sanguine of this to name two of the species "postcarbonica." The species described are: *Ammodiscus concavus*, *Bigenerina* cf. *eximia*, *Dentalina bradyi*, *Geinitzina postcarbonica*, *Lituola?* sp., *Monogenerina atava*, *M. nodosariforsis*, *Nodosaria postcarbonica*, *Tretaxis conica*, and *Textularia gibbosa*. Probably from the same stratum from which these Foraminifera came, we find specimens of a typical *Schwagerina*. The same stratum

[1] Girty, "The Guadalupian Fauna," *Professional Paper 58, U. S. Geological Survey*, 1909.

[2] *Loc. cit.*

farther south has furnished us with an abundance of Fusulina very similar to, if not identical with, *F. longissima.* It is worthy of note that Schwagerinas and *F. longissima* are associated in some of the European deposits, but among somewhat older faunas. When we consider that Schwagerina is totally unknown in the Atlantic province and consider the route which it must have taken in reaching this region—Eastern Himalayas, China, California—it is but natural to expect it to appear in a somewhat higher horizon than that from which it started, since it is improbable that all the barriers of Eurasia and America were removed to furnish it simultaneous passage. For this reason its appearance among an open-sea Permo-Carboniferous micro-foraminiferal fauna of the Atlantic province may be explained. It should be remarked, however, that some species of Schwagerina are found in rocks of Permo-Carboniferous age in Eurasia.

Of the sponges there are two genera worked out, that permit of direct comparison. They are Amblysiphonella and Steinmannia. *Amblysiphonella prosseri,* from the Topeka limestone in Kansas and a horizon not any higher at Weeping Water, Nebraska, is closely allied to a species from the Lower Productus limestone or Amb beds of the Salt Range in India, while Steinmannia described by Dr. Girty from the Allen limestone seems to have a close relative in the specimens of that genus in the Middle and Upper Productus limestone of the Salt Range. The fact of peculiar interest is that the relative positions of the two in Kansas is reversed from what it is in India, Amblysiphonella occurring at a higher horizon than Steinmannia.

There are two species of corals common to the Kansas section and the Artinskian—Dolomite Suite—of the Donnez Basin of southeastern Russia: *Michilinia eugeneae,* which is confined to Series I and II in the Kansas rocks, and *Lophophyllum profundum,* occurring, probably, throughout the section from Series I to IV inclusive.

Several of our brachiopods appear to have relatives abroad. *Chonetes mesolobus* and *C. laevis* (not *C. geinitzi*) occur in the Schwagerina horizon in the Ural-Timen region, while in Kansas they are confined to Series I, and are separated from Schwagerina by 1,800 feet of deposits. *Chonetes variolatus* and *C. verneuilanis* are found in the Cora and Schwagerina horizons and in the Kansas section are

confined to the rocks below Series IV. *Chonetes granulifer* has a similar range in the Uralian deposits, but begins in the Allen limestone and continues into the Florence flint in the Kansas rocks. *Spirifer cameratus, Spiriferina kentuckiensis,* and *Hustedia mormoni* or a near relative of it are found as high as the Schwagerina limestone, and two of them, or their near allies, occur throughout the Artinskian and Permian in Russia. In the Kansas succession Spiriferina reaches the Elmdale formation, and the other two the Neva limestone. Two of them range through the whole Salt Range deposits. *Cryptacanthia compacta* or a species almost identical with it ranges through the Russian deposits into the Artinsk, and is confined to Series I and II of our section. Cleiothysis has a similar range in Europe, throughout the Permian in Asia, and to the Fort Riley limestone in the Mississippi Valley region. Shells of types of *Productus boliviensis* and *P. lineatus* are associated with the rocks from the Allen to the Oread limestone. Their Russian range is from the Cora to the Artinsk inclusive. *Productus cora,* in the strict sense, is probably confined to the rocks below the Deer Creek limestone, and those above are referable to Norwood's *P. pratteni* which continues to the Permian. In Europe *P. cora* ranges into the Artinsk. *Productus gruenwaldti* and *P. punctatus* range through the Artinsk, and are unknown above the Howard limestone of our section. *Productus nebraskensis* is quite as abundant in Series IV as at any horizon below, while (as understood by Tschernyschew) it is confined to the Omphalotrochus horizon.[1] However, its near relative ranges through the Artinsk. *Dielasma bovidens* occurs up to the base of the Wreford limestone and through the Schwagerina limestone of the Urals. The species of Squamularia are hard to differentiate and, with their allies, are ubiquitous throughout Eurasian Anthracolithic rocks. They are unknown above the Howard limestone.

[1] In the original description this species was supposed to be a sharp-beaked form. On the contrary it is an attached form, in its early stages presenting nearly every characteristic of a true Strophalosia, except that the adductor scars are arborescent. Mr. Greene, who is working on this species, has not yet completed his studies and it cannot be stated yet whether this character is a case of parallel development, or whether this is a species of Productus which has taken on the habit of attachment in its young stage. If the latter be true, it is the only case of an attached Productus with which I happen to be acquainted.

Pugnax utah is confined to the Schwagerina horizon on the one hand and in our rocks is ubiquitous, ranging from the Cherokee shales to the Fort Riley limestone. These remarks are also true of *Ambocoelia planoconvexa* which is common to the whole Indian Permian. Our ubiquitous *Derbya crassa* seems to be confined to the Omphalotrochus-Cora horizons. Jakowlew has recently shown that *Meekellia striaticostata* is synonymous with *M. eximia,* which makes it ubiquitous in both Russia and America.

All the pelecypods mentioned below have been found in the Permo-Carboniferous of the Donnez, Oka, and Kljasma basins of Russia as described by Jakowlew. Only their range in the Kansas deposits will be mentioned.

Pseudomonotis is a group of shells for the most part confined to the Permian deposits of the world, though running over into the Mesozoic. Nearly all the known species of it found in America are found in the Drum limestone, Stage D of the Kansas succession. They occur again in the Kickapoo limestone and become especially abundant and characteristic in Series IV and above.

These remarks apply in a general way to *Pleurophorus subcostatus,* the American equivalent of *P. costatus. Lima krotowi* or its affine is confined to Stages I and II. *Acanthipecten carboniferus* is confined to Series I and II and Stages F and G, except a specimen found at a much higher horizon in northern Oklahoma last fall. *Entolium aviculatum* has been recorded by Dr. Girty from the Wreford limestone. *Pleurophorus oblongus* has only been reported from the Drum limestone by Dr. Bennett. *Edmondia Nebraskensis* ranges from the Drum limestone well into the upper part of Series IV. *Schizodus wheeleri* is found from the Dennis limestone (and perhaps from the Fort Scott limestone) into the upper part of Series IV. Streblopteria is known from the Drum limestone to the Fort Riley limestone, Dr. Girty recording it from the latter horizon. *Pleurophorus subcuneatus* is unknown below Stage J. The Bakewellias and Cyrtodontarcas have not yet been faunally worked out. A species has been recorded from the Willard shales. However, they are very rare until much higher strata are reached.

It will be noted that in the faunal comparisons and discussions, the Chase and Marion stages have not been treated quite so fully as

those of the underlying horizons. The reason is that the faunules have not been quite so fully worked out and tabulated. However, they have been gone over in a preliminary manner and found to contain nothing, so far as I have observed, that is contradictory to the evidence presented.

From the foregoing discussion of the Kansas faunas and the comparison of the elements in common (for it is largely upon the elements in common that intercontinental correlations must be based) with those of Russia, there seems little reason for considering the Kansas faunas of Series III older than the Schwagerina-Cora horizons of Russia. Indeed the evidence is quite as strong in the opposite direction.

GENERAL SUMMARY AND CONCLUSIONS

From what has been said it is apparent that during the Carboniferous period on the continents of Europe and America there was a long period of time during which favorable conditions obtained and the fauna was relatively varied, but, as many of the genera and species became paracmic, they were, in varying degrees, unable to adjust themselves to the changing conditions introduced more or less gradually with the Permian, and perished. Those capable of least resistance perished first, and in the basal Permian we have a fauna made up of two elements in response to the physical and biologic conditions. First, the hardier forms which had passed their culumation and were on their decline. This is especially true of the brachiopods. They disappeared, not more, perhaps, from want of favorable conditions than from loss of vitality. Second, the pelecypods differentiated—possibly receiving recruits from other regions—and became the characteristic forms of the Permian.

The one part of the Pennsylvanian fauna "grew old and died" assisted by changing conditions, while that part which had not previously reached the acme of its existence differentiated into a fauna capable of inhabiting the more and more concentrated waters of the Permian seas. These classes of organisms being similar on the two continents produced similar results, whether or not the species were identical.

We may now summarize the bearing of the evidence of the stratig-

raphy and the invertebrate fossils on the age of the rocks under the following seven heads:

1. The physical conditions and climatic history of the Permian of America and Europe were similar. They were marked by the deposits of dolomites, limestones, gypsum, and red sediments on both continents.

2. The upper Pennsylvanian sediments were in each case marked by a superabundance of Fusulinas, and by other similar faunal elements.

3. The fauna of the lower Permian—including the Artinsk—is characterized by the development of a peculiar molluscan element and its dominance over the Molluscoidea.

4. The general comparison of the elements in common in the upper Pennsylvanian faunas indicates that Series III is as young as the uppermost Carboniferous faunas of Europe.

5. The great reduction of Pennsylvanian species near the close of Series III and the base of Series IV, together with the introduction of species in the basal part of Series IV which become very important and characteristic elements in the faunas of the higher rocks, seems to justify the provisional location of the Pennsylvanian-Permian boundary at the base of Series IV.

6. The general similarity of the faunas of Series IV and the overlying rocks of the Kansas basin with the Permian of Europe seems to be suggestive of their homotaxy.

7. The extent of Permian time represented in the Texas Panhandle region by the unconformity of the Permian Red Beds and the Triassic Dockum beds is unknown.

What the final evidence of the fossil vertebrates and plants may be remains, to some extent, to be determined. With the rapid progress now being made in the study of the former on both continents and the rapid collection of the plants now in progress in the western Mississippi basin, we may look in the near future to a fuller determination of the homotaxy of American and European Permian. In the meantime I am inclined to take the evidence of the physical conditions and the invertebrate fossils at its face value and draw the conclusions in accordance with it.

PETROLOGY OF THE SOUTH CAROLINA GRANITES[1]

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OUTLINE OF THE GEOLOGY OF THE CRYSTALLINE AREA

The South Carolina area of crystalline rocks extends northwestward from the fall-line, is roughly triangular in shape, and forms a part of the eastern crystalline area which extends southwestward from New York to northern central Alabama.

Until the recently established State Geological Survey of Earle Sloan, this region had received almost no geological study since the state surveys of M. Toumey in 1844–47 (1848 date of final report) and of O. M. Lieber in 1855–60.

The Blue Ridge crosses the extreme northwest corner of the state in a narrow mountainous belt, the higher peaks of which have an extreme elevation of 3,500 feet. Between this mountainous belt on the northwest and the fall-line on the southeast is included the greater part of the crystalline area—the Piedmont province. Its principal physiographic features, in common with the same province toward the northeast and southwest, are the broad rolling upland surface, the valleys carved in the upland, and the minor residuals which rise above the upland. The higher elevations over the region are stated by Sloan to range from 700 to 900 feet above sea-level, with the beds of the major streams averaging 200 feet lower.[2]

Metamorphic crystalline rocks compose the principal part of this region. They include crystalline schists and gneisses derived from both igneous and sedimentary masses, altered chiefly through recrystallization and textural modifications, the most apparent of which is schistosity. The original rocks from which the schists and gneisses are derived are so extremely altered in many places that all trace of their characters is lost.

Among the principal metamorphic igneous rocks are granite-gneisses, hornblende schists, and quartz-sericite schists. In com-

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, p. 505.

position and texture the gneisses indicate derivation from original granites. They are usually of light color, fine- to medium-grained texture, and contain, in addition to quartz and mica (biotite with frequently some muscovite), much microcline and some acid plagioclase (oligoclase). The hornblende schists (amphibolites) are composed usually of hornblende and feldspar (albite and oligoclase), some quartz and titaniferous iron ore, with epidote, zoisite, and in places calcite. The quartz-sericite schists are derived from fine-grained bedded porphyry tuffs,[1] corresponding in composition to granite and quartz monzonite. These altered tuffs have been noted chiefly in the immediate vicinity of the gold deposits of York, Lancaster, and Chesterfield counties, and presumably have large areal extent. Where noted in the vicinity of the gold deposits, their alteration has been chiefly one of silicification and recrystallization.[2]

Metamorphic rocks of sedimentary origin include chiefly quartz schist, quartz-sericite schist, quartz-biotite schist, sericite schist, and crystalline limestone. The limestones are usually associated with the schists into which they may grade along their edges within a short distance.[3] They have been noted chiefly in the northwestern part of the state in Cherokee, Laurens, Oconee, and Union counties, where variation is from ordinary blue limestones to white coarse-grained marbles. True foliation is usually most apparent near the margins or edges of the beds. These limestones are usually magnesian, ranging, according to Sloan,[4] from less than 1 per cent. up to 39.72 per cent. of magnesium carbonate. Ordinarily the blue limestones are the more calcareous and the light-colored ones dolomitic. Other minerals than the carbonates, chiefly silicates (amphibole, pyroxene, and mica) and quartz, are contained in the limestones in places.

Granite, pegmatite, and diabase are the principal unaltered igneous rocks. Their general character and field relations to the surrounding rocks indicate that they were intruded subsequent to the

[1] L. C. Graton, *Bull. No. 293*, U. S. Geological Survey, 1906, pp. 15, 16, 78, 79; Geo. H. Williams, *Journal of Geology*, Vol. II (1894), pp. 28 f.

[2] L. C. Graton, *op. cit.*, p. 16.

[3] *Ibid.*, p. 19.

[4] Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 256–61.

principal metamorphism affecting the metamorphic rocks described above. Greatly altered masses of porphyry are intruded into the surrounding schists in places, especially in Chesterfield and Lancaster counties.[1]

The granite and pegmatite are closely related in composition, and each is discussed in detail in the subsequent pages of this paper.

Dikes of diabase, ranging up to 200 or more feet in width, are frequently noted throughout the crystalline region, where they may cut any of the rocks described above. These vary in texture from fine- to moderately coarse-grained, and in composition from olivine to olivine-free rocks, are regarded as Mesozoic in age, and represent the latest intrusions in the region.

At Hornsboro, in Chesterfield County, there is a small area of Juratrias sandstones penetrated by diabase dikes—an extension of the Wadesboro, N. C., area into South Carolina.

The geological structure of the South Carolina crystalline region conforms, so far as is known, with other portions of the Atlantic Piedmont province. The rocks are much folded, having northeasterly strikes, and usually dipping at large angles either to the southeast or northwest.

Very little advance has been made toward determining the age relations of the rocks of this region since the work of the earlier geologists. Lieber[2] regarded the rocks of the King's Mountain region as Silurian. Kerr[3] later assigned the rocks of this area to the Huronian. Becker[4] and Nitze[5] considered the rocks of the central Carolinas to be Algonkian. Williams[6] placed the surface volcanic rocks and their associated tuffs as pre-Cambrian. Recent work by Graton[7] in the King's Mountain region resulted in his assigning all the rocks of the region, except the diabase dikes, "Monroe" beds, and sands of the coastal plain, to the pre-Cambrian. In mapping the "Pisgah Folio" in North Carolina, the extreme southern portion of which includes

[1] L. C. Graton, *op. cit.*, pp. 22, 23.

[2] O. M. Lieber, *Geological Survey of South Carolina*, Vol. III, p. 149.

[3] W. C. Kerr, *Geology of North Carolina*, 1875, p. 133.

[4] G. F. Becker, *16th Ann. Rept. U. S. Geological Survey*, 1895, Part III, p. 260.

[5] H. B. C. Nitze, *Bull. No. 3*, North Carolina Geological Survey, 1896, p. 44.

[6] G. H. Williams, *Journal of Geology*, Vol. II (1894), pp. 28 f.

[7] L. C. Graton, *op. cit.*, 1906, pp. 29–31.

a small part of Greenville and Pickens counties, S. C., Keith[1] refers the Henderson granite to the Archean, the Brevard schists, including fine-grained black and dark schists, with lentils of limestone, to the Cambrian, and the Whiteside granite doubtfully to post-Cambrian age.

Excepting the Whiteside granite mapped by Keith in the "Pisgah Folio" as of doubtful post-Cambrian age, Paleozoic granites are yet unknown in the South. For this reason and because of the absence of definite evidence to the contrary, the South Carolina granites are provisionally assigned by the writer as pre-Cambrian in age.

THE GRANITES

DISTRIBUTION

Granite occurs in each of the twenty-one counties composing the crystalline area described above. During the summer of 1908, quarrying was in progress in nine of the twenty-one counties. The principal producing areas extended southwestward across the state along or near the fall-line in Lancaster, Fairfield, Richland, Lexington, and Edgefield counties, and in the extreme northwest portion of the state in Pickens County. Both massive (even-granular and porphyritic) and foliated (schistose) types of granite are frequent over the crystalline area. These are described in detail in the following pages under a number of individual types based chiefly on differences of physical characters and to a less degree on composition.

MINERAL COMPOSITION

The South Carolina granites—mixtures of feldspar, quartz, and biotite—correspond closely in mineral composition with the granites of the southeast Atlantic states in general. They are prevailingly biotite granites. Muscovite, in association with biotite, is a subordinate constituent in a part of the granites of Edgefield, Fairfield, Oconee, and York counties, and is a principal constituent in a reddish-gray granite found near Liberty Hill post-office in Kershaw County. Hornblende has been met with in the granite of one locality only, namely, one mile south of Winnsboro on the Winnsboro-Rockton

[1] Arthur Keith, *Geologic Atlas of the United States*, "Pisgah Folio," No. 147, 1907, "North Carolina–South Carolina."

road. It is subordinate to biotite but is in sufficient amount to designate the granite a hornblende-bearing biotite granite (p. 742).

The great preponderance of biotite granites over others in South Carolina is shown in the following tabulation:

I.	Biotite granite	40
II.	Muscovite granite	1
III.	Muscovite-bearing biotite granite	8
IV.	Hornblende-bearing biotite granite	1
V.	Biotite granite-gneiss	14
VI.	Muscovite-bearing biotite granite-gneiss	4

The feldspars, as indicated in the table of chemical analyses below, include nearly equal mixtures of potassic (orthoclase and microcline) and sodic-lime (plagioclase) varieties. Microcline is equal to and occasionally greater in amount than orthoclase in some sections, and in others it entirely fails. Microperthite, intergrowths of orthoclase with a second feldspar (albite), is very constantly present. Plagioclase near oligoclase (soda-lime feldspar) is present in large amount, and in most cases is equal to or greater in amount than potash feldspar. Examination of the analyses below brings out this fact of high soda content, which is confirmed by the optical studies of thin sections of the granites.

Besides the principal minerals enumerated above, there occur accessory apatite, zircon, magnetite, sphene, and rutile, together with secondary chlorite, epidote, a light-colored mica, and occasionally some other minerals. These are the usual accessories in granite.

CHEMICAL COMPOSITION

The following analyses give a fair idea of the range in composition of the granites described below.

The chemical composition is characterized by a percentage of SiO_2 ranging from 68.70 to 70.70 per cent., with an average for 17 analyses of 69.46 per cent., which is about the normal silica percentage for granites. Of the 18 available analyses of the South Carolina granites, five show more SiO_2 than is indicated in the maximum percentage (Col. VI, 70.70 per cent.) of the table given on p. 735, ranging for the five from 70.90 to 73.26 per cent. The iron oxides, magnesia, and lime show some variation, but on the whole each is

reasonably uniform, and is neither very high nor very low. Most of the lime in these analyses is to be attributed to the prevailingly large amount of soda-lime feldspar present in the rocks.

CHEMICAL ANALYSES OF SOUTH CAROLINA GRANITES AND GNEISSES*

	I	II	III	IV	V	VI	VII	VIII
SiO_2	68.70	68.80	68.90	69.79	70.54	70.70	69.95	68.94
Al_2O_3	15.49	15.73	15.75	16.08	14.56	15.63	15.19	15.27
Fe_2O_3	1.10	2.14	1.16	1.01†	1.06	1.14‡	1.20	1.80
FeO	3.73	1.57	1.49	1.66†	1.62	1.24‡	1.61	2.04
MgO	0.86	1.16	0.74	0.53	0.78	0.30	0.69	1.04
CaO	1.70	1.64	2.66	1.73	1.28	2.14‡	1.94	2.24
Na_2O	3.09	3.45	4.76	4.07	3.97	3.86	3.91	3.49
K_2O	3.36	4.54	3.49	4.45	5.37	4.76	4.57	4.31
Igni.	0.81	0.33	0.18	0.49†	0.27	0.48	0.39	0.29
TiO_2	0.84	0.45	0.36	0.41†	0.60	0.24‡	0.43	0.50
MnO	Trace	Trace	Trace	Trace	Trace	Trace	0.01	Trace
P_2O_5	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
SO_3	0.13	Trace	Trace	Trace	0.06	Trace	Trace	0.02
	99.51	99.81	99.49	100.67	100.11	100.49	99.88	99.92

* Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 174–225.

† Average of 2 analyses.

‡ One analysis.

I. Porphyritic biotite granite, Clouds Creek, 4.7 miles north of Batesburg, Saluda County.

II. Biotite granite, Cold Point Station, Laurens County.

III. Biotite granite, Jackson's Quarry, 0.5 mile north of Clover, York County.

IV. Average of 3 analyses, including biotite granite from Anderson Quarry, Fairfield County, biotite granite from Excelsior Quarry, Lancaster County, and biotite granite from Leitzsey Quarry, Newberry County.

V. Biotite granite, Benjamin Quarry, 4 miles east of Greenwood, Greenwood County.

VI. Average of 2 analyses, including biotite granite from Flatrock Quarry, Union County, and Keystone Granite Co.'s Quarry, Spartanburg County.

VII. Average of 13 analyses of biotite granites.

VIII. Average of 4 analyses of granite-gneisses, including Ware Shoals, Laurens and Abbeville counties, Beverly Quarry, Pickens County, Pendleton Quarry, Anderson County, and Bates Quarry, Lexington County.

The sum of the alkalies ranges from 6.45 to 9.34 per cent., with an average of 8.48 per cent. for 13 analyses of the South Carolina granites. In the relation between K_2O and Na_2O the former slightly predominates, ranging from 3.36 per cent. to 5.37 per cent. Na_2O

varies in the analyses from 3.09 per cent. to 4.76 per cent., and may equal or even appreciably exceed (Col. III) K_2O. Na_2O shows a total average for the analyses of 3.81 per cent., and K_2O of 4.33 per cent., a difference or excess of 0.52 per cent. of K_2O. The exact composition of the biotite in these granites being unknown, it is not possible to compute accurately the percentage of potash feldspar from the analyses, but most of the K_2O should be calculated as orthoclase.

In each analysis Na_2O has been calculated as albite, and similarly CaO as anorthite. By adding the albite to the anorthite a soda-lime feldspar is obtained which ranges from Ab_3An_1 to Ab_4An_1 in composition, corresponding to a basic oligoclase. This does not completely accord, in every case, with optical study of the thin sections, which frequently show the presence of microperthite, intergrowths of albite with the potash feldspar, and the undoubted presence of Na_2O in the potash feldspar.

In 13 of the 18 available analyses of South Carolina granites, the percentage of Na_2O approximately equals or is but slightly less than that of K_2O; in 5, Na_2O exceeds K_2O; and in only one is there a considerable excess of K_2O over Na_2O. Molecularly, Na_2O exceeds K_2O in each analysis. On the basis then of essentially equal potash and soda, these granities are, to follow Brögger,[1] quartz monzonites and not normal granites.

In defining the limits of intermediate rock-types between granites and diorites, the range of orthoclase in quartz monzonites is stated by Mr. Lindgren[2] as follows: "In the quartz monzonites I would give this mineral (orthoclase) a range from 20 per cent. to 40 per cent., all in an assumed total of 60 per cent. feldspars. The rocks containing more than 40 per cent. orthoclase would then be classed as granites, there being scarcely room for another family between the quartz-monzonites and the granites."

On this basis it will be seen by reference to the table of analyses that if all the K_2O is calculated as orthoclase, the maximum range in

[1] *Die Eruptionsfolge der triadischen Emptiogesteinen bei Predazzo in Sudtyrol* (Kristiania, 1895).

[2] "Granodiorite and Other Intermediate Rocks," *Amer. Jour. Sci.*, Vol. IX (1900), p. 279.

this mineral would not exceed 32 per cent., and an average would be about 25.5 per cent. The total feldspar content of these granites, based on the analyses above, averages about 66.8 per cent. proportioned about as follows: 25.5 per cent. potash feldspar and 41.25 per cent. soda-lime feldspar.

Attention is further directed in the analyses to the constant presence of titanium in very appreciable amount, ranging in the form of TiO_2 from 0.24 to 0.48 per cent. The microscope indicates its principal sources to be in sphene and titaniferous iron oxides, and to some extent as rutile filaments in the quartz. Manganese and phosphorus are noted, usually in traces only.

TYPES OF THE GRANITES

All the granites are biotite granites, muscovite being frequently present in subordinate amount and hornblende failing entirely except in a single locality. They vary in structure from massive to schistose, and in texture from even-granular to porphyritic rocks, and may be grouped on this basis into (1) even-granular massive granites, (2) porphyritic granites, and (3) schistose or foliated granites—granite-gneisses.

The even-granular and porphyritic granites are textural variations of the same rock-mass and are sometimes indicated in the same quarry, but, in such cases, the porphyritic texture is likely to be of a less emphasized or pronounced type than is observed in parts of Georgia and North Carolina. The granite-gneisses have closely similar chemical and mineral composition to the massive granites, from which they were derived and from which they differ principally, in pronounced schistose structure secondarily induced in them by dynamic metamorphism.

PETROGRAPHY

EVEN-GRANULAR GRANITES

General characteristics.—The even-granular granites have wide but variable distribution throughout the crystalline area of the state. They vary from fine- to medium-grained rocks in texture, less often coarse-grained, and are usually some shade of gray in color—light, medium, and dark blue-gray shades being frequent. In many localities a part of the feldspathic constituent is either of slight or

pronounced red color, which imparts a mixed reddish-gray color to the rock, the depth of which is proportional to the intensity of red color of the feldspar.

The even-granular granites are described below under the following types, based on differences which are best brought out under the individual descriptions: The Winnsboro types (including light gray

FIG. 1.—Rion Quarry of the Winnsboro Granite Corporation, South Carolina.

and dark-blue gray), the Greenwood–Cold Point gray, the Bowling Green–Clover light gray, and the Columbia red gray.

The Winnsboro types.—The granites near Winnsboro in Fairfield County are of three varieties, which strongly contrast with each other in hand specimens but are essentially similar mineralogically. One of these is a hornblende-bearing biotite granite, described on p. 742, and is more coarsely crystalline than the other varieties, which are biotite granites. Based on difference of color, the biotite granites are known to the trade as (1) the Winnsboro light gray, and (2) the Winnsboro dark-blue gray, the first being extensively quarried

for general building purposes, the latter for monumental stock. These do not differ essentially in mineralogy but bear no resemblance to each other in the hand specimens.

The light-gray variety (Figs. 1 and 2) has no closely similar type, except mineralogically, in the South. Quartz, orthoclase (partly intergrown with albite as microperthite), microcline, oligoclase, biotite, apatite, zircon, and iron oxide, with the usual secondary minerals, make it up. Microperthite and micropegmatite are abun-

FIG. 2.—Near view of a part of quarry face shown in Fig. 1.

dant. Micropoikilitic structure (inclosures of irregular rounded quartz, feldspar, and quartz-feldspar intergrowths—micropegmatite) is rather characteristic of the larger feldspar individuals.

The dark blue-gray variety of fine crystallization has many closely similar representatives, chief among which are the granites of the Excelsior Quarry in Lancaster County and near Newberry in Newberry County, S. C.; the Oglesby-Lexington dark blue-gray granite of Elbert and Oglethorpe counties, Ga.;[1] the Mooresville fine-grained

[1] *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 188–224; *Amer. Geologist*, Vol. XXVII (1901), pp. 202, 203.

granite in Iredell County, N. C.;[1] and the Richmond-Fredericksburg dark blue-gray granite in Virginia.[2] The granite of the Guilford and Waltersville Quarry near Guilford, Md., is somewhat similar, but is of lighter color and coarser crystallization. As would be expected, these granites may show minor variations in texture and color, but these are so slight that but little difference can be discerned between them in the hand specimens. Orthoclase, much microcline, oligoclase, quartz, biotite, apatite, zircon, and magnetite make up the principal primary minerals composing the Winnsboro blue-gray type of granite.

An average of three analyses of the Winnsboro dark blue-gray type of biotite granite from South Carolina is given below in Col. I and is compared with analyses of the similar type from Georgia (Col. II) and North Carolina (Col. III).

	I	II	III
SiO_2..........	69.79	69.59	66.01
Al_2O_3.........	16.08	16.84	17.44
Fe_2O_3........	2.85	1.24	5.62
MgO.........	0.53	0.76	1.11
CaO..........	1.73	2.67	1.44
Na_2O.........	4.07	4.77	5.06
K_2O..........	4.45	4.93	3.16

I. Average of 3 analyses of biotite granite from Anderson Quarry, Fairfield County, Excelsior Quarry, Lancaster County, and Leitzsey Quarry, Newberry County, S. C. *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 252–54.

II. Average of 2 analyses of biotite granite from Diamond Blue Granite Co.'s Quarry, Oglethorpe County, and Hill Quarry, Elbert County, Ga. *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 191, 241.

III. Biotite granite from Johnson Quarry, near Mooresville, Iredell County, N. C. *North Carolina Geological Survey*, 1906, Bull. No. 2, p. 84.

It will be observed from the analyses that Na_2O and K_2O are essentially equal in the South Carolina and Georgia granites of this type, and in the similar North Carolina type Na_2O greatly exceeds K_2O. Calculating CaO and Na_2O in the analyses to anorthite and albite the following percentages of these minerals are obtained: South

[1] *Journal of Geology*, Vol. XII (1904), pp. 392, 393; *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 81–85.

[2] *Bull. Geol. Soc. Amer.*, Vol. XVII (1906), pp. 528, 529.

Carolina, 8.62 per cent. anorthite and 35.11 per cent. albite, corresponding to Ab_4An_1; Georgia, 13.34 per cent. anorthite and 40.35 per cent. albite, corresponding to Ab_3An_1; North Carolina, 7.23 per cent. anorthite and 42.44 per cent. albite, corresponding to Ab_6An_1. The ratio of potash to soda-lime feldspar in the Winnsboro dark blue-gray type of granite is: South Carolina, 1:1.7; Georgia, 1:1.9; North Carolina, 1:2.6.

The gray granites from Columbia, Pacolet, and near Carlisle in Union County, S. C., vary from the type of the Winnsboro blue-

FIG. 3.—Bowlder outcrop of the Winnsboro Granite Corporation's light-gray granite at Rion, Fairfield County, S. C.

gray granite chiefly in lighter color and coarser crystallization. Hand specimens of the granite from the different localities contrast strongly with each other in many cases, but they are essentially similar in mineral and chemical composition.

The Greenwood–Cold Point types.—The granites at Quarry in Greenwood County, and at Cold Point farther north in Lancaster County, though essentially similar mineralogically, are of two varieties which bear but slight resemblance to each other in the hand specimens. The granite at Quarry is more coarsely crystalline with bluish opalescent quartz, while the Cold Point variety is more finely crystalline and the quartz varies from colorless to moderately dark smoky in color. The feldspars in both varieties (gray granites) are

of a faint reddish cast which is more pronounced in the Quarry granite. The principal minerals in these granites are orthoclase (partly intergrown with albite as microperthite), microcline, plagioclase near oligoclase, quartz, biotite, sphene, apatite, and zircon, with the usual secondary minerals which result from the partial alteration of feldspar and biotite. Microcline and plagioclase are present in largest amount. Quartz and feldspar are partly intergrown in granophyric structure, indicating overlapping in the periods of crystallization of these minerals. Carlsbad twins of the potash feldspar are noted both in hand specimens and under the microscope.

Chemical analyses of these granites are given in Cols. II and V in the table of analyses on p. 735. The principal constituents in each analysis are here given for convenience of ready comparison.

	Cold Point Laurens County	Quarry Greenwood County
SiO_2	68.80	70.54
Al_2O_3	15.73	14.56
Fe_2O_3	2.14	1.06
FeO	1.57	1.62
MgO	1.16	0.78
CaO	1.64	1.28
Na_2O	3.45	3.97
K_2O	4.54	5.37

A comparison of these analyses shows the Quarry granite to be slightly more acid and to contain about 2 per cent. more of total alkalies. In both, the percentage of K_2O exceeds that of Na_2O by a fraction more than 1 per cent., but molecularly the latter exceeds the former.

The granite exposed along the road one mile south of Winnsboro in Fairfield County varies but slightly from the Quarry type, the principal difference being the presence of additional hornblende to biotite in the former, which is apparent only in thin sections. As previously stated on p. 733, this is the only granite in the state studied by me in which hornblende occurs. Its principal minerals are orthoclase, microcline, oligoclase, quartz, biotite, hornblende, apatite, zircon, sphene, and the usual secondary accessory minerals. A part of the orthoclase is intergrown with plagioclase (albite) as microperthite. Of the feldspars, microcline and plagioclase are

present in largest amount. Micropoikilitic and granophyric structures are common to the feldspars.

The Bowling Green–Clover light-gray granite.—The extensive granite area in the northern central part of York County in the vicinity of Bowling Green and Clover is a medium-textured light-gray biotite granite, closely similar in mineralogy, color, and texture to the Mount Airy granite in Surry County, N. C. It varies from even-granular to porphyritic in texture, but in the porphyritic facies of the rock the feldspar phenocrysts are not very abundant and though frequently of large size, and sometimes showing crystal boundaries, they are usually without crystal outline and grade into the similar ground-mass constituent. In common with the porphyritic granites of the southern states, the feldspar phenocrysts of the porphyritic facies of this type inclose shreds of biotite, equal in size to those of the ground-mass.

This granite consists chiefly of orthoclase, microcline, plagioclase (oligoclase), quartz, biotite, occasional muscovite, together with accessory apatite, zircon, and iron oxide, and secondary chlorite, epidote, colorless mica, and kaolin. Both feldspar and biotite show some alteration in the surface portions of the granite, the former appearing white opaque and chalky from partial kaolinization, the latter showing irregular areas of reddish-brown staining from iron oxide immediately adjacent to the biotite from partial leaching. Intergrowths of orthoclase with plagioclase (albite) as microperthite, and of feldspar with quartz as micropegmatite are frequent. The larger feldspar individuals carry frequent inclosures of feldspar chiefly, quartz, and felsdpar-quartz intergrowths (micropegmatite). Microcline exceeds orthoclase in some sections and is much less in others.

A chemical analysis of this type of granite is given in Col. III of the table of analyses on p. 735. Its close similarity in composition to that of the Mount Airy granite, North Carolina, is indicated in the following analyses, p. 744.

The most noteworthy feature in these analyses is the excess of Na_2O over K_2O. On the basis of the percentages of Na_2O and K_2O in the analyses, the York County, S. C., granite contains 53.41 per cent. of soda-lime feldspar corresponding to Ab_3An_1, and the Mount

Airy, North Carolina, granite, 52.71 per cent. The ratio of potash to soda-lime feldspar in the York County granite is 1:2.6; Mount Airy granite, 1:3.6.

	York County South Carolina	Mount Airy North Carolina
SiO_2	68.90	70.70
Al_2O_3	15.75	16.50
Fe_2O_3	1.16	2.34
FeO	1.49	
MgO	0.74	0.29
CaO	2.66	2.96
Na_2O	4.76	4.56
K_2O	3.49	2.45

The Columbia red-gray granite.—The coarse crystalline red-gray granite quarried at the Smith Branch (County) Quarry, two miles northwest of Columbia, is taken as the type. It does not differ essentially in mineralogy from the gray types described above, although it bears no resemblance to them or to any granites in the other southern states, in the hand specimens. The granite of the Casparis Quarry near Lexington and to the north of Batesburg in Saluda County, S. C., differs from this type only in finer crystallization. In each of these localities the feldspar has pronounced red color, which gives to the granite its characteristic shade. More or less tendency toward porphyritic texture is exhibited in this type of granite. Orthoclase, microcline, oligoclase, quartz, biotite, apatite, magnetite, and the usual secondary minerals are present. Twinning on the Carlsbad law is noted in the potash feldspar. A chemical analysis of this type has not been made as yet, but the thin sections indicate the usual richness in soda-lime feldspar.

PORPHYRITIC GRANITES

Porphyritic granites are common over many parts of the crystalline area in South Carolina, but extensive continuous areas in which porphyritic texture is developed are apparently less frequent than in Georgia and North Carolina. Though porphyritic texture is quite freely developed in many of the granite areas, it either grades within rather short intervals into the more dominant even-granular texture or else is not of so pronounced a type. Like the even-granu-

lar granites into which they grade, the porphyritic granites are biotite granites. The potash feldspar phenocrysts vary in size, form, and color. They rarely exceed 30^{mm} in length, are both allotriomorphic and idiomorphic in outline, white or pink in color, often twinned on the Carlsbad law, contain inclusions of biotite, and are without marked orientation in any of the areas studied.

Two rather unusual types of porphyritic granite in the southern states, the Clouds Creek blue-gray and the Heath Springs coarse gray granite, are described below.

The Clouds Creek blue-gray granite.—This type of granite, occurring in an extensive belt in the southeastern part of Saluda County along Clouds and Moores creeks, does not resemble megascopically the granite of any known locality in the South. In hand specimens it is not unlike the coarse-textured augite-hornblende-biotite syenite found southwest of Concord in Cabarrus County, N. C., but differs from the latter in containing more quartz and in the absence of augite and hornblende.

The rock is a massive porphyritic biotite granite (quartz monzonite) of blue-gray color, the ground-mass of which consists of anhedra averaging in size from 2 to 10^{mm} (quartz, 4 to 10^{mm}, biotite, 2 to 4^{mm}, and feldspar 2 to $10+^{mm}$). Porphyritic texture is not very pronounced because of the regular gradation of the feldspar phenocrysts into the similar ground-mass constituent without apparent difference in physical characters shown in the feldspar of the phenocrysts and the ground-mass. The quartz is of slight bluish opalescent color. Feldspar is prevailingly blue gray. In places much of it is nearly white, frequently showing a very faint greenish cast. Cleavage is well developed and Carlsbad twinning is common. The feldspar phenocrysts grade into the ground-mass constituent, are of irregular outline (roughly rounded), from 10 to 25^{mm} and more in diameter, usually blue gray in color though frequently nearly white, highly lustrous and cleavable, and contain inclosures of the ground-mass biotite.

Thin sections show microcline, orthoclase (partly intergrown with albite as microperthite), plagioclase near oligoclase, quartz, and biotite, with secondary chlorite, iron oxide, and colorless mica. Carlsbad and albite twinning are frequent in the feldspars which show some

alteration to a colorless mica and kaolin. Biotite shows partial alteration to chlorite and iron oxide, the latter segregated in the biotite much after the fashion of inclusions.

A chemical analysis of this type, given on p. 735 in Col. I, is noteworthy because it shows nearly equal percentages of Na_2O and K_2O and molecularly the former exceeds the latter. Calculating the CaO and Na_2O to anorthite and albite, a plagioclase feldspar is obtained corresponding to Ab_4An_1, amounting to 33.54 per cent., which exceeds potash feldspar by 13.52 per cent., were all the K_2O calculated as orthoclase.

FIG. 4.—Bowlder outcrop of the Heath Springs coarse-grained porphyritic granite. Three miles southwest of Heath Springs, S. C.

The Heath Springs coarse gray granite.—This variety of granite, exposed in large bowlder outcrops (Fig. 4) several miles southwest of Heath Springs in Lancaster County, is closely similar mineralogically, in texture, and in color to the granite of the Wadesboro-Rockingham area[1] to the northeast in Anson and Richmond counties, N. C. The granite is a porphyritic biotite granite of coarse-grained texture and mixed reddish- and greenish-gray color. The feldspars range from 1 to 25^{mm} in size, are highly lustrous and cleavable, mostly of irregular outline, though in part flat-tabular, averaging about 7^{mm} broad by 20^{mm} long, twinned on the Carlsbad law, and partly reddish and bluish green in color. The feldspar phenocrysts grade into the same ground-mass constituent, thus rendering the porphyritic texture less pronounced, and inclose plates and shreds

[1] *Journal of Geology*, Vol. XII (1904), pp. 385, 386; *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 15–20.

of biotite. Quartz, 1 to 7^{mm} in size, inclines to moderate dark smoky color, and biotite, 0.25 to 5^{mm} in areas up to 10^{mm} in size.

Its principal minerals are orthoclase, microcline, plagioclase (oligoclase), quartz, biotite, sphene, apatite, zircon, and iron oxide, with secondary chlorite, epidote, a little colorless mica, and kaolin. The thin sections examined showed soda-lime feldspar (oligoclase) in excess of the potash feldspar (orthoclase and microcline). A chemical analysis has not been made of this granite nor of the similar one from the North Carolina area, but the feldspar content is apparently somewhat above the average for normal granites.

GRANITE-GNEISSES

Gneisses of granitic composition comprise one of the principal rock-types in the South Carolina crystalline region. Many of these were derived from original massive granites, and are invariably of the mica type, usually biotite; sometimes subordinate muscovite is associated with biotite. The granite-gneisses are essentially identical in mineral composition (table of analyses, p. 735) with the massive granites, from which the former differ chiefly in the banded structure secondarily induced into them by metamorphism. The principal minerals are quartz, orthoclase (largely microperthite), microcline, plagioclase (oligoclase), biotite, a little muscovite, apatite, zircon, sphene, and secondary chlorite and epidote. Recrystallization and orientation of the essential minerals result in a schistose structure. The gneissic banding may be regular or irregular and contorted, usually the latter; the bands are of varying thicknesses, and are composed of alternating ones of light- (chiefly feldspar and quartz) and dark- (chiefly biotite) colored minerals. Like the massive granites, the gneisses show similar variation in color and texture (even-granular to porphyritic).

The Beverly granite-gneiss.—This type, a contorted biotite granite-gneiss of medium- to dark-gray color and medium-grained texture, resembles quite closely the granite-gneiss of the Lithonia and Odessadale areas in Georgia,[1] and the Rockyface Mountain area, Alexander County, in North Carolina.[2] It is more coarsely crystalline than the

[1] *Georgia Geological Survey,* 1902, Bull. No. 9A, pp. 78, 79, 125 f.

[2] *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 160 f.

gneiss of the Georgia localities. The minerals are orthoclase, microcline, oligoclase, quartz, biotite, muscovite, sphene, zircon, apatite, iron oxide, and secondary chlorite, epidote, and colorless mica. Orthoclase is partly intergrown with a second feldspar as microperthite. Microcline shows evidence of having been derived in part from orthoclase. Micropegmatite intergrowths as small areas are indicated, and some of the larger feldspar individuals show micropoikilitic structure (inclosures of rounded quartz chiefly). Granulation of the quartz and feldspar is pronounced and orientation of the biotite is usually well marked.

The South Carolina[1] granite-gneiss (Col. 1) is compared chemically with the Georgia[2] gneisses (Cols. 2 and 3) in the following analyses:

	Beverly South Carolina	Lithonia* Georgia	Odessadale Georgia
SiO_2	68.15	75.09	76.37
Al_2O_3	14.30	13.86	13.31
Fe_2O_3†	5.20	.95	1.21
MgO	1.04	.16	0.10
CaO	2.80	.98	1.13
Na_2O	3.80	3.87	4.02
K_2O	3.84	4.87	3.68

* Average of 5 analyses.
† Total iron estimated as Fe_2O_3.

Examination of these analyses shows at once the greater acidity of the Georgia gneisses over the gneiss from South Carolina, in the large excess of silica, and the smaller amounts of lime, magnesia, and iron oxide. In the percentages of alkalies, Na_2O and K_2O, the difference is less apparent. Molecularly, Na_2O exceeds K_2O in each case, but when CaO and Na_2O are calculated to anorthite and albite the difference is more striking. For the South Carolina type total plagioclase is 45.86 per cent., for Lithonia and Odessadale, Ga., 28.05 and 39.10 per cent., respectively. Also, the plagioclase in the Georgia localities is more acid than that from the South Carolina locality.

THE APLITES AND THE PEGMATITES

Aplites.—Aplite dikes are only occasionally met with in the South Carolina granites. They were noted by me only at three localities,

[1] *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, p. 250.

[2] *Georgia Geological Survey*, 1902, Bull. No. 9A, p. 243.

namely, at Smith Branch (County) Quarry near Columbia, the Anderson Quarry in Fairfield County, and at the Casparis Quarry near Lexington. In the quarry near Columbia, aplite dikes are rather numerous, ranging up to four feet in thickness. They are uniformly reddish brown in color and so dense and fine-grained in texture that the minerals cannot be distinguished by the naked eye. The principal minerals, under the microscope, are orthoclase, some microcline, oligoclase, quartz, a little biotite, apatite, and secondary chlorite and epidote. At the Anderson Quarry in Fairfield County, the aplites, ranging in thickness from 1 to 12 inches, are banded with

FIG. 5.—Bared slope of granite-gneiss at Beverley Quarry, Beverly, Pickens County, S. C.

pegmatite. They are very fine-grained in texture and of light-gray color, with scant biotite visible to the unaided eye. The minerals are microcline, orthoclase (partly microperthite), some oligoclase, quartz, very little biotite, occasional muscovite, zircon, and accessory chlorite and epidote.

Pegmatites.—Pegmatites are frequent over the region and at times attain considerable size. They are granitic, mineralogically, without unusual or rare minerals observed in them, and may cut any of the rocks of the crystalline complex. The mica is usually biotite with frequently some muscovite associated with it. In the quarry at Pacolet black tourmaline is a constituent of some of the pegmatites.

In Abbeville, Anderson, Greenville, Oconee, and Pickens counties the pegmatite dikes vary from 9 to 20 feet in thickness, and, as indicated in the table of analyses below, the feldspar of these pegmatites is the potash variety.

ANALYSES OF FELDSPAR FROM SOUTH CAROLINA PEGMATITES*

	I	II	III	IV
SiO_2	60.79	62.26	65.60	67.30
Al_2O_3	22.57	20.41	19.45	18.21
Fe_2O_3	0.18	0.31	0.71	0.79
MgO	0.23	0.78	0.13	0.14
CaO	0.24	0.19	0.18	0.14
Na_2O	2.72	1.41	2.02	2.41
K_2O	11.01	12.71	11.34	11.14
Igni.	1.90	1.54	0.63	0.06
TiO_2	.....	Trace	Trace	Trace
P_2O_5	0.09	....	....	....
SO_3	Trace	....	Trace	....
	99.73	99.61	100.19	100.19

* Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 142–49.

I. Feldspar from pegmatite dike 8.5 miles southeast of Greenville, Greenville County, S. C.

II. Feldspar from pegmatite dike 12.5 miles northwest of Walhalla, Oconee County, S. C.

III. Feldspar from pegmatite dike 3.7 miles N. 70° W. of Pickens, Pickens County, S. C.

IV. Feldspar from pegmatite dike 6 miles N. 55° W. of Central, Oconee County, S. C.

Several varieties of pegmatite were distinguished by Graton[1] in the tin belt of the King's Mountain area, the four most common of which, in the probable order of their formation, are: (1) Pegmatite, usually of light color and not very coarse grained, composed of microcline, quartz, oligoclase, orthoclase, muscovite, with in places numerous small red garnets and ilmenite. Crushing is apparent in much of the rock. (2) Pegmatite of light color, somewhat foliated, with feldspar as the chief constituent. The feldspar consists of orthoclase, intergrown with albite, and separate small individual grains of albite, quartz, and biotite, with associated small prisms of monazite, and in many places flakes of primary graphite. These are sometimes worked in the western part of Cherokee County for monazite. (3) Pegmatite of very light color and fairly coarse grained, with quartz and feldspar as the only constituents in most places, but muscovite and cassiterite become essential constituents locally. Microcline is abundant, penetrated by grains of albite and slender tongues of

[1] L. C. Graton, *Bull. No. 293*, U. S. Geological Survey, 1906, pp. 20–23.

quartz. (4) Pegmatite of the fourth class is coarse grained and consists chiefly of quartz and muscovite, with feldspar absent or only sparingly present. Feldspar is locally abundant. Cassiterite is an important constituent in places, and spodumene, apatite, and probably lithiophilite are noted.

JOINT SYSTEMS

Two systems of joints intersect the granites in the South Carolina quarries, namely, a vertical set and a horizontal set. These do not in all cases have the same degree of development, nor are the two systems always developed in the same quarry. Vertical joints, the commonest type, may have inclinations of as much as 50° to 60° with variable intervals of spacing. In the northeast quadrant the joints which extend approximately north-northeast and east-northeast are of about equal development; in the northwest quadrant those which extend approximately west-northwest comprise the dominant system. Only a few of the joints measured extended E.-W. and N.-S. The system of horizontal joints, which in general follow the surface configuration of the rocks, is less often developed in the granite of the South Carolina quarries than in the granites of the other southern states.

ELEVENTH SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS IN STOCKHOLM, 1910

J. G. ANDERSSON
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At the tenth meeting of the International Geological Congress in Mexico, 1906, the Swedish geologists invited the congress to hold its next session in Stockholm, an invititaon that was unanimously accepted. In view of the extensvie preliminary work occasioned by the projected excursions, a wish was expressed by the Swedes that the meeting in question, which should really have taken place in three years' time, might be postponed until 1910. The decision was left to the Swedish geologists, and subsequently 1910 was fixed upon by the Swedish organizing convocation for the meeting in Stockholm.

The initiative in inviting the International Geological Congress to Sweden was taken by the Geological Society in Stockholm on May 4, 1905, when a committee was appointed, which raised the sum required for the undertaking by means of state grants, etc., and issued the invitation on the occasion of the session in Mexico.

A general meeting of the Swedish geologists was held in Stockholm on March 5, 1907, for the purpose of drawing up a general program for the work of organization. This meeting also instructed the previously established committee to officiate as Executive Committee for future arrangements. On the retirement of the former director of the Geological Survey of Sweden, Professor A. E. Törnebohm, his place, as president of the committee, was taken by Professor G. de Geer. The treasurer of the committee is Professor H. Bäckström, while Professor J. G. Andersson, the present director of the Geological Survey of Sweden, officiates as general secretary.

The Swedish Executive Committee considers it advisable that *preference* should be given to the discussion of such questions at the meeting of the congress in Stockholm, as the actual geological phenomena of Sweden or of the polar regions can throw light upon. Particu-

lar attention should thus be devoted to the following domains of geological science:

1. *The Geology of Archaean Rocks.*
2. *The Geology of the Quaternary Period.* (Especially climatic changes in late- and post-glacial times.)
3. *The Geology of the Polar Regions.*
4. *Applied Geology.* (Especially extent and distribution of the supplies of iron-ore in the world.)

Numerous, extensive excursions have been planned in connection with the Congress:

Before the Meeting:

1. Northern Sweden. (Norrland.)	
a) Large overthrusts, post-archaean eruptives, etc.	20 days
b) The ore-fields of Gellivare and Kirunavara.	10 days
c) Quaternary formations in Jämtland.	10 days
d) Quaternary formations in Norrbotten.	10 days
2. Spitzbergen.	About 3 weeks
3. Peat-beds in central Sweden.	6 days

During the Meeting:

Several one-day excursions.

After the Meeting:

1. Five simultaneous excursions in Southern Sweden, excepting Scania.	12 days
a) Archaean rocks.	
b) Cambrian-Silurian beds.	
c) Quaternary deposits.	
d) Ores.	
e) General geology.	
2. (To follow 1.) Three simultaneous excursions in Scania.	7 days
a) Cambrian-Silurian beds.	
b) Mesozoic beds.	
c) Quaternary beds.	

The first excursions (to Spitzbergen and Norrland) begin about July 25, the meeting of the congress takes place apout August 18–26, and the last excursions (in Scania) end in the middle of September.

This program is subject to alterations; the present scheme is provisional.

All correspondence having to do with the coming congress should be addressed to the general secretary, Professor J. S. Andersson, Stockholm (3), Sweden.

CLAY DUNES

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Numerous instances of dunes composed of *sand* can be found in almost all countries, especially along the coast or in dry regions where the geological formations are of a sandy character, but dunes made up of *clay* have never, so far as I have been able to ascertain, been reported.

During the last winter the writer was engaged in making a reconnoissance soil survey of south Texas for the United States Department of Agriculture and in the prosecution of the work encountered near the mouth of the Rio Grande some long, narrow clay ridges, the formation of which was at first very puzzling. These ridges were sometimes several miles long, 30 feet high, and not over 200 or 300 yards in width. Occurring in a section of very level, semimarsh land and being often covered with mesquite, cactus, and palmetto, while the surrounding country shows only a growth of coarse salt grass, they form a very striking feature of the landscape. How had they been formed? To what agency were they due?

One day while driving north of the mouth of the Arroyo Colorado, an old outlet of the Rio Grande, there appeared in the distance what looked to be a mile or more stretch of almost white drifting sand. The soil around was a heavy, marshy clay. On reaching the ridge, which was probably 20 feet high, what appeared, at first glance, to be grains of sand were seen blowing across the bare surface. A closer examination, however, showed them to be granules of clay which could be easily broken down between the fingers and when moistened became very plastic and sticky. Here was the explanation of the formation of these clay ridges; they were really clay dunes.

Further observation showed that these "clay dunes" were almost always associated with a lagoon. Where such relation does not exist at the present time it is doubtless due to the filling of the lagoon by sediments brought down by the river. During dry weather these lagoons become partially or entirely dry, and the mud then cracks

and curls up, giving the wind a chance to get hold upon the material which is then broken up by its action into small grains and driven out upon the surrounding higher land. The wind velocity in this section is rather high and prevailingly from the southeast; therefore the dunes are formed principally upon the northwest side of the lagoons. As soon as the small granules of clay are blown out of the lagoons they encounter vegetation and are stopped. The first rain causes them to break down and coalesce, thus forming a compact mass which is no longer moved by the wind. By this process these clay ridges or clay dunes have been built up many feet above the surrounding lands.

In many instances these lagoons have no outlet and the amount of material in the ridges, if placed in the depressions, would be sufficient to bring them to the level of the surrounding country. It looks very much as if the material forming the dunes had been scooped out and piled along the banks by a great dredge. In fact, many of these depressions have doubtless been formed, or at least enlarged, in just this manner, Nature having hollowed them out with her great scoop—the wind.

These "clay dunes" are confined to the coast country from a point directly east of Raymondville southward to and possibly beyond the mouth of the Rio Grande. They are always found in the low coast country, generally within 5 miles of the Laguna Madre. The question why they occur here and not at the mouth of the Mississippi and other rivers requires some explanation. This will be found, it is believed, in the rather peculiar climate conditions of this section.

A study of the precipitation records in this section will show that the rains are very irregular in their occurrence and that long periods of deficient rainfall may be followed by others of very heavy precipitation. The annual precipitation at Brownsville has varied from 8.88 inches in 1870 to 60.06 in 1886, and the monthly from 0.0 to as much as 30.57. During the long periods when there is little or no rainfall the lagoons nearly all become dry while in a more humid climate, where the rains are more frequent, sufficient time for drying out is not given and no clay dunes are found. The Rio Grande is the only large river in the country where such conditions exist and this is the reason why these clay dunes are confined to this locality.

Reviews

Igneous Rocks. Vol. I, Composition, Texture and Classification. By Joseph P. Iddings. New York: John Wiley & Sons, 1909.

The application of modern ideas of physics and chemistry to the study of the rocks may be seen, more and more, in recent publications, and the results of these newer investigations make it necessary to look at the problems of petrology from an entirely new point of view. It is rather remarkable, and an indication of the need of a systematic presentation of the subject, that within the past few months there have appeared two volumes, following essentially similar plans, and differing entirely from previous works on petrology, namely: Professor Harker's *Natural History of Igneous Rocks*, and Professor Iddings' *Igneous Rocks.*

Professor Iddings introduces the subject with a consideration of the chemical composition of igneous rocks as a whole without regard to the mineral constituents, and he describes the various graphical methods used by petrographers to express the proportions of chemical elements in these rocks.

The magma, solidifying as a rock, takes, in general, the form of a mass of crystals with definite chemical and physical characters, and more or less glass. The relations to each other of the so-called pyrogenetic, or primary, minerals are shown by the presence in them of elements which occur together in the same groups in Mendeléeff's table. Consequently many of the minerals in a given rock are characterized by their content of different amounts of the same element.

The principles of physics and chemistry applicable to rock magmas are fully discussed. Rock magmas are now believed by everyone to be, not simple melts, but solutions of minerals at high temperatures which may act like solutions of other compounds at lower temperatures. In the latter, the reactions taking place, the processes of solidification which convert them into glasses or crystals, and the physical characters and molecular constitution of the liquid solutions are more easily understood than they are in rock magmas at high temperatures and pressures. In order to study properly the facts of physical chemistry, there are discussed the kinetic theory of gases, liquids, and solids, the melting points of rock minerals, and the physical characters and chemical reactions of solutions. After this preliminary statement of principles, the discussion of the chemi-

cal and physical behaviors of molten magmas is begun with the consideration of the chemical reactions which give rise to minerals, and which would probably take place, within the earth, between the elements occurring in igneous rocks. From these studies the laws governing the association of certain minerals in the rocks are deduced.

In consequence of changes of physical conditions, the molten magma separates into solids, gases, and, to a small extent, liquids. These processes are complicated by variable factors such as change of chemical reactions or degree of supersaturation under different conditions of temperature and pressure produced by the movements of eruption. The causes of this separation, the order and the effect of supersaturation upon it, the effect of viscosity upon the rate, and the separation taking place in isomorphous compounds and eutectic mixtures, are discussed.

Following this presentation of the subject of the separation of substances from solution, is a chapter on the crystallization and texture of igneous rocks, the terms used being those recently proposed by Cross, Iddings, Pirsson, and Washington.[1] The degree of crystallization of a rock magma and the amount of glass affect both the mineral constituents of the resulting rock and its texture. The extent of crystallization, the magnitude, shape, and arrangement of the crystals or amorphous parts, and the factors which influence texture are fully described and illustrated.

The differentiation, or splitting-up of a homogeneous rock magma into chemically unlike portions, is next considered. The evidences of such separation are divided into two groups: (1) Igneous rocks differing in chemical composition in different parts of the same body; and (2) igneous rocks of different compositions associated in regular manner with reference to place of occurrence and time of eruption, and possessing such chemical characteristics that their previous existence as components of a homogeneous magma is clearly indicated.

The agencies which are likely to affect the character of a rock magma are changes of temperature, pressure, or gas content, and Professor Iddings considers the way in which each of these may act upon certain physical or chemical characters of the magma. They may change the density of the liquid magma in certain parts and produce convection currents, or they may change the viscosity and modify the diffusivity. A change in osmotic pressure would produce a variation in the molecular concentration in different portions, a change in saturation or chemical equilibrium would affect the crystallization and the resulting minerals, and a change in the character of the solidification would affect the texture of the rock. The

[1] *Jour. Geol.*, Vol. XIV, 1906, pp. 692–707.

chapter closes with a brief sketch of various hypotheses that have been suggested in explanation of differentiation, and a statement of the processes of magma eruption.

A discussion of structures and the modes of occurrence of extrusive and intrusive igneous rocks concludes part one. By the term structure, Professor Iddings follows the more recent usage, restricting it to those "large features of rock bodies which have been produced by cracking, by fracturing and aggregation, or which may be brought about by erosion," the term texture being applied to the microscopic features.

The second part of the volume, which consists of 121 pages, is taken up with nomenclature and classification of igneous rocks. After a short historical sketch, the author presents an adaption of the current qualitative systems of classification. The definitions of the rocks are essentially those of Rosenbusch and of Zirkel given in terms of mineral composition and texture with no expression of views as to the possible genetic relations between them. Professor Iddings divides the rocks into five groups based on the dominance of (1) quartz, (2) quartz and feldspar, (3) feldspar, (4) feldspar and feldspathoid, (5) feldspathoid. Each of these is separated into divisions based on the character of the preponderant feldspathic constituent, and these, in turn, into divisions with little or much ferromagnesian minerals. The final divisions are into phanerocrystalline and aphanitic rocks; the latter having two subdivisions, those of cenotypal and those of paleotypal habit.

The last chapter of the book, consisting of 61 pages, is taken up with the quantitative classification of Cross, Iddings, Pirsson, and Washington, and is an abridgment of the system published by them in 1902.[1] The rules for the calculation of the norm have been rewritten and are now much clearer than formerly, the explanatory notes interpolated in the older work being omitted.

It is only in this second part of Professor Iddings' book that it differs widely from that of Professor Harker. In both books the treatment of the newer petrology is similar, but the two writers differ entirely upon the question of classifications, although they agree that the existing systems are unsystematic, unsatisfactory, and confusing. Professor Harker has given but 18 pages to classifications, and one could wish that he had further developed his own ideas on the subject, especially in the way of a classification based upon eutectics, such as was suggested by Becker[2] and Vogt.[3]

[1] *Jour. Geol.*, Vol. X, 1902, pp. 555–690.

[2] Geo. F. Becker, *21st An. U. S. G. S.*, III, 1899–1900, pp. 519, 520.

[3] J. H. L. Vogt, "Ueber anchi-eutektische und anchi-monomineralische Eruptivgesteine," *Norsk Geol. Tidsskr.*, 1905, Vol. I, No. 1.

It is his view that "the establishment of a genetic classification is dependent only on a fuller knowledge of facts and principles," and "a systematic treatment of igneous rocks on these lines . . . . is not to be expected in the immediate future." Professor Iddings has made no attempt at a genetic classification, believing that there are too many factors influencing genetic relations to permit of their use. He thinks that the chemical composition of an igneous rock is "its most fundamental character . . . . and is therefore of greatest importance for its correlation with other igneous rocks."

Professor Iddings' book is a most valuable addition to the literature of petrology and will be welcomed by students for its presentation of the new view of those problems which, to a large extent, have heretofore been given only in scattered publications, representing the work of such men as Day and his colleagues in the Geophysical Laboratory, Doelter, and Vogt.

The book is well printed on good paper, the half-tones are clear, and the line drawings are neat. The book is bound in blue cloth uniformly with the same author's *Rock Minerals.*

A. J.

Through the Yukon and Alaska. By T. A. Rickard. I–XIII, pp. 384. San Francisco: Mining and Scientific Press, 1909.

Few if any travelers in Alaska have made so many and such accurate observations as Mr. Rickard, and of those who have published similar journals, no one has included so much of real value to those interested in the resources of the Yukon district and Alaska, or in the mining activities of those countries. The author has told in a delightful way many of the incidents of travel, and has taken pains to give accurately the history of some of the most remarkable discoveries in these northern countries. The romantic history of the Treadwell mines, the discovery of gold on the Klondike, the wonderful development at Fairbanks, and the story of the discovery and exploitation of the Nome beach, are here given in a fuller and more interesting way than they have elsewhere appeared. Mr. Rickard has retold many of the stories associated with life in Alaska, during the exciting periods from 1895 to 1900: thus the fake discovery of a Silent City, the story of Soapy Smith and his gang of desperadoes, the incidents associated with the great stampede over White Pass and Chilcoot Pass, the life at Dawson, on Cleary Creek, and the story of many events at Nome which have afforded material for novels and magazine articles, are given in a very readable form. The book is, however, more than a

narrative of travel, for the author has described the mining conditions and mining processes with an ability that few can equal. The book is well illustrated and a very welcome addition to the literature on Alaska.

W. W. A.

Schistosity by Crystallization. By FRED. EUGENE WRIGHT. *Am. Jour. Sci.*, Vol. XXII, September, 1906.

The schistose and gneissose textures of many metamorphic rocks have been ascribed to the orienting influence of pressures with a stress difference acting during the recrystallization of the rock in its new environment—solution taking place along the line of greatest strain and deposition along the line of least resistance and normal to the maximum stress. In such cases the rock cleavage is due to the parallel arrangement of its mineral components in planes perpendicular to the line of greatest stress.

Conditions of experiment in which crystallization under unequal strains could take place were effected by using cubes of glasses made by chilling melts of different minerals rapidly, and by heating these to the point at which crystallization first began, the viscous glass at that temperature being still in a state of fair rigidity, and capable of supporting a certain amount of unequal strain. Textures similar to those of certain metamorphic rocks were produced in this way, and an experimental confirmation of the theoretical deductions thus obtained.

Quartz as a Geological Thermometer. By FRED. EUGENE WRIGHT AND ESPER S. LARSEN. *Am. Jour. Sci.*, Fourth Series, Vol. XXVII, p. 162.

This paper, which is a review and discussion of experiments made by the writers in the Geophysical Laboratory of the Carnegie Institution at Washington, is an important contribution to the knowledge of mineral genesis. By means of the electric resistance microscope the birefringence and circular polarization of quartz plates at various temperatures were measured and the inversion point (575°) was accurately determined.

The birefringence of the quartz plates decreases gradually from 0° to 575°, at which point the decrease is very rapid. Beyond this point the birefringence increases slightly. The inversion was observed both on heating and cooling and the changes are constant and sharply marked. There is also a marked change in the angle of circular polarization at the inversion temperatures and abrupt change in the coefficient of expansion

which is expressed both on heating and cooling and a change in the heat capacity.

Quartz formed at the low temperature is hexagonal and trapezohedral-tetratohedral, while that formed at the high temperature is probably hexagonal and trapezohedral-hemihedral. It is found that these crystallographic relations are expressed in the circular polarization of the two varieties. Intergrowths of right- and left-handed quartzes are more frequent and more regular in boundary lines in the quartz formed at low temperatures and the etched figures show more regular and more sharply defined twinning. Quartz formed at the higher temperatures and subsequently cooled may show the effects of inversion by shattering or latent weakness inherent in such crystals may be disclosed by etching in hydrofluoric acid. Large clear quartzes free from cracks have probably never reached the inversion temperature.

Quartzes from veins and geodes and certain vein pegmatites are in general clear and free from intricate fracture-cracks and show regular intergrowths of right- and left-handed quartzes; they are frequently twinned and the outline of the twinned areas is usually regular. The quartzes from graphic and granite pegmatites, granites, and porphyries are smaller in size, frequently fractured and cracked. They rarely show intergrowths of right- and left-handed individuals and the outlines of such intergrowths may or may not be regular. The observed characteristics of the first group of quartzes are those deduced theoretically for low-temperature quartzes, while the features of the second group are those deduced theoretically for quartzes formed above 575°. This places the temperature of final solidification of an intrusive granite mass above 575°.

It is hoped that these investigations will be extended to the quartz formed by contact metamorphic processes. As pointed out by Lindgren these deposits without doubt were formed above the critical temperature of water. By the use of the quartz thermometer on carefully selected material the precipitation point of many minerals of the contact zones could be approximated much more closely than has yet been done.

Tridymite, it is pointed out, forms at 800°, beyond which the high-temperature quartz is unstable. Definite data concerning the behavior of SiO_2 through a wide range of temperatures and at ordinary pressures are thus supplied. Perhaps the pressures do not greatly affect the nature of crystallization though they do affect the solubility of quartz. In the great majority of the rhyolites and quartz-porphyries of Montana, Nevada, and Colorado, it is, in the experience of the reviewer, the most conspicuous of the phenocrysts. Nearly everywhere it is resorbed. The phenocrysts

of quartz were clearly formed before the magma rose to the surface and their corroded or embayed condition is due to resorption by the magma. It is generally assumed that the relief of pressure causes a change in equilibrium and as a result of relief the magma ceases to precipitate quartz and dissolves some of that which has been precipitated. Does the presence of quartz instead of tridymite show that the temperature of solidification was less than 800°? In the case of granitic rocks where the last crystals formed are an eutectic, the temperatures there are low, but in the porphyries containing resorbed quartz the latter must have been present in excess of the eutectic for the temperature and pressure prevailing at the time.

If the pressures do not seriously affect the quartz thermometer then it follows that the excess quartz in porphyries (phenocrysts) does not begin to be precipitated until the lava has cooled to 800°. From this and the great abundance and wide distribution of the resorbed quartz phenocrysts, it follows that the siliceous lavas probably rise to the surface very slowly—so slowly that the large quartz crystals may be precipitated and again resorbed while the lava which ultimately solidifies as a glassy rock has cooled to 800°.

If calcite, pyrite, or some other common vein mineral should supply another point near 100° C., certain vexed problems related to the genesis of an important class of metalliferous deposits could easily be solved.

W. H. E.

Seventeenth Annual Report of the Ontario Bureau of Mines, 1908. Published by order of the Legislative Assembly of Ontario. THOS. W. GIBSON, Deputy Minister of Mines, Toronto, 1908.

The report includes a statistical review of the mineral productions of Ontario for 1907, technological and geological notes on various mines by E. T. Corkill, a description of the geology of Thunder Bay–Algoma Boundary by Arthur S. Parsons, of the Iron Ranges east of Lake Nipigon by A. P. Coleman and E. S. Moore, and a review of the iron and steel industry of Ontario by George Cleghorn Mackenzie.

The value of the mineral production for 1907 was $25,019,373.00, an increase of 12 per cent. over 1906. Six metals yielded nearly fifteen million dollars. These, in order of their value, are silver, iron, nickel (ore value), copper, cobalt, gold. The non-metallic products yielded above ten million dollars.

The splendid showing is due chiefly to activities in silver mining at Cobalt, which produced $6,301,095.00 in silver, cobalt, arsenic, and nickel.

At this camp four companies have installed concentrators to treat the low-grade ores.

The nickel ores yielded $2,271,616.00, but the product had a refined value of nearly four times that sum. Nearly all of this production was recovered by two companies. About a million dollars' worth of copper was recovered as a by-product of the nickel ores, and the Superior and Bruce mines produced also a relatively small amout of this metal.

W. H. E.

Epitome of the Economic Geology of New Mexico. By FAYETTE A. JONES. Published by Direction of the New Mexico Bureau of Immigration, Albuquerque, New Mexico, 1908.

This well-arranged, neatly bound volume of 47 pages is sure to meet with the favor of prospectors and others interested in the mineral resources of New Mexico. The minerals and other products of present or prospective economic importance include coal, copper, silver, gold, lead, zinc, iron, manganese, molybdenum, fluorite, alum, salt, gypsum, sulphur, mica, asbestos, meerschaum, turquoise, graphite, petroleum, natural gas, guano, marble, stone, clay, and mineral paint. A feature of the booklet is a catalogue showing the distribution of various minerals.

W. H. E.

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ERRATUM

Page 24: *Quercus milleri* sp. nov. preoccupied by a species described by Ettingshausen. Should read *Quercus calvertonensis* sp. nov.

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